Nuclear Power Plant Emergencies

What Physicians and Other Health Care Providers Need to Know about Radioactive Iodine and Potassium Iodide

C. Gregory Smith, MD, MPH

Epidemiology Section

NC Department of Health and Human Services

Acknowledgements

- NC Division of Emergency Management
- NC Radiation Protection Section
- Food and Drug Administration
- New York Department of Health
- Vermont Department of Health
- Pennsylvania Department of Health
- Maryland Department of Health and Mental Hygiene
- Dr. Jan Wolff -National Institutes of Health

Radiation Basics

- Different types of radiation
- Biological effects of radiation
  - Somatic cell effects
  - Germ cell effects
- How radiation is detected and measured
- Regulatory dose limits
- How dose can be avoided or minimized

Radioactivity

Process of emitting radiation

(energy either as rays or particles which are generated by transforming atoms. It is called "ionizing" because it is energetic enough to dislodge electrons from their orbits, producing "ions".

Principal types of radiation produced by fission products and heavy elements in a nuclear reactor are:

Alpha, Beta, Gamma and Neutron Radiation.

- Alpha **-similar to ionized nuclei or helium atoms--- 2 +, 2 N**
- Beta **-particles similar to electrons, or if + charged, positrons**
- Gamma Radiation **-an electromagnetic wave**

Types of Radiation

Type of Radiation	Alpha	Beta	Gamma
Charge	+2	-1	0
Origin	Nucleus	Nucleus	Nucleus
Range in Air	Several centimeters	Several meters	Hundreds of meters
Average Penetration	Superficial skin layers	About 1 cm soft tissue	Thru the body; Inches of Pb
Type of Hazard	Internal	External/ Internal	External/ Internal
End Result	Helium Atom	Free Electron	Head on e collision

Radiation Units

Descriptive Term	Property
Curie	Amount of radioactive material transforming at 3.7×10^{10} disintegrations/sec
Roentgen	Measure of ionization in air produced by X-ray or gamma radiation
Rad	Radiation energy absorbed by a material
Rem	Radiation energy absorbed by biological systems

Wilhem Roentgen (Germany)   Pierre and Marie Curie (France)

Wilhem Conrad Roentgen
1845-1923
1895 Discovered unknown rays which he termed "X-rays"
1901 First Nobel Laureate in physics

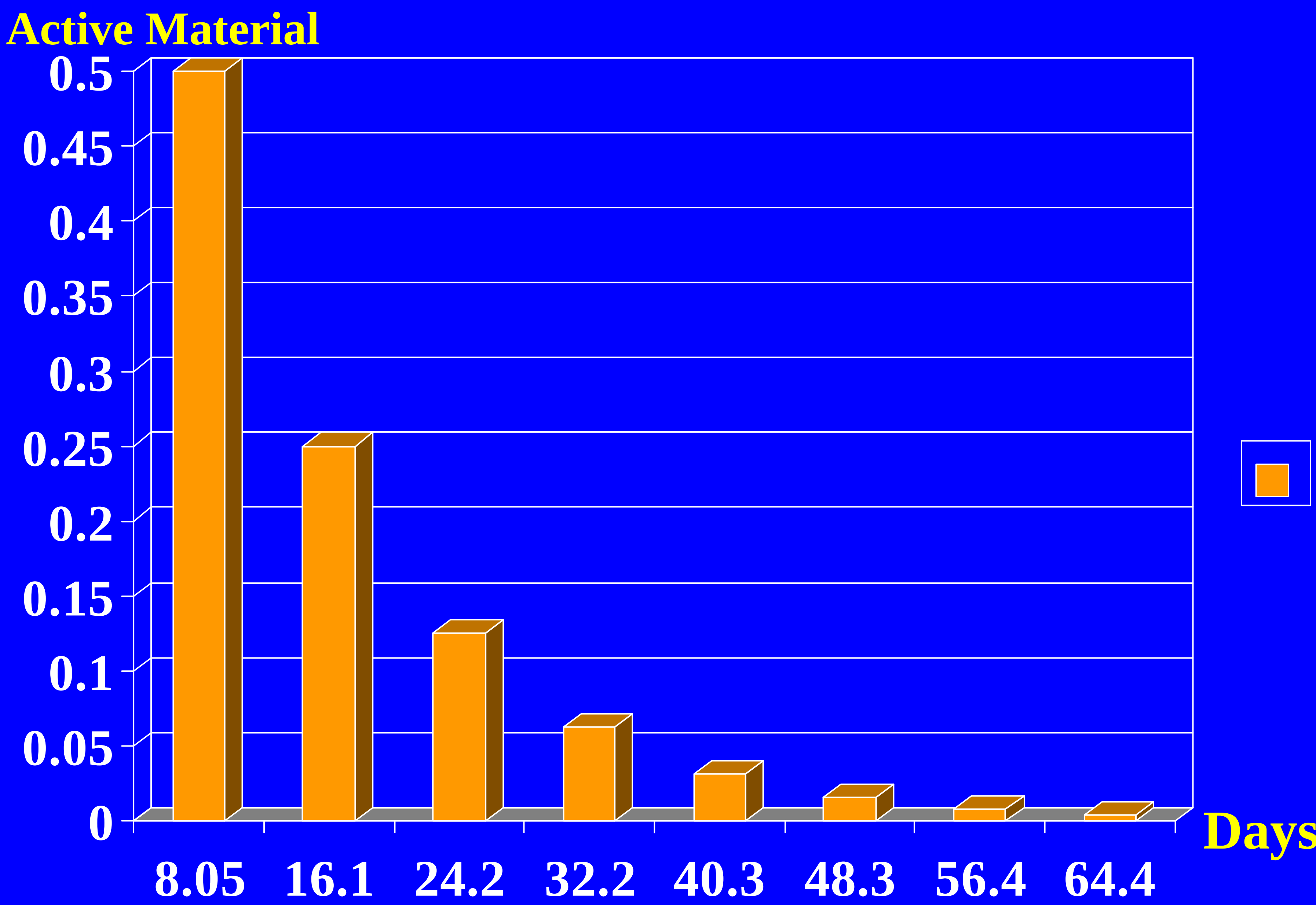
Pierre Curie and Marie Curie 1867-1934
1903 Nobel Laureates in Physics
Marie - Invented word "radioactivity"
- Discovered radium and polonium
1911 Second Nobel Prize - Chemistry
1934 Died Age 66 from Aplastic Anemia

More About Radiation Units

- For x-rays, gamma and beta radiation:

  1 Roentgen ≈1 Rad ≈1 Rem
- Low levels of individual dose are expressed as millirems (mrem)
- Rad and Rem are sometimes replaced by international system units:
  - the Gray (Gy) 1Gy = 100 rad
  - the Sievert (Sv) 1 Sv = 100 rem

Radioactive Decay: Iodine-131 Half Life (Beta/Gamma)

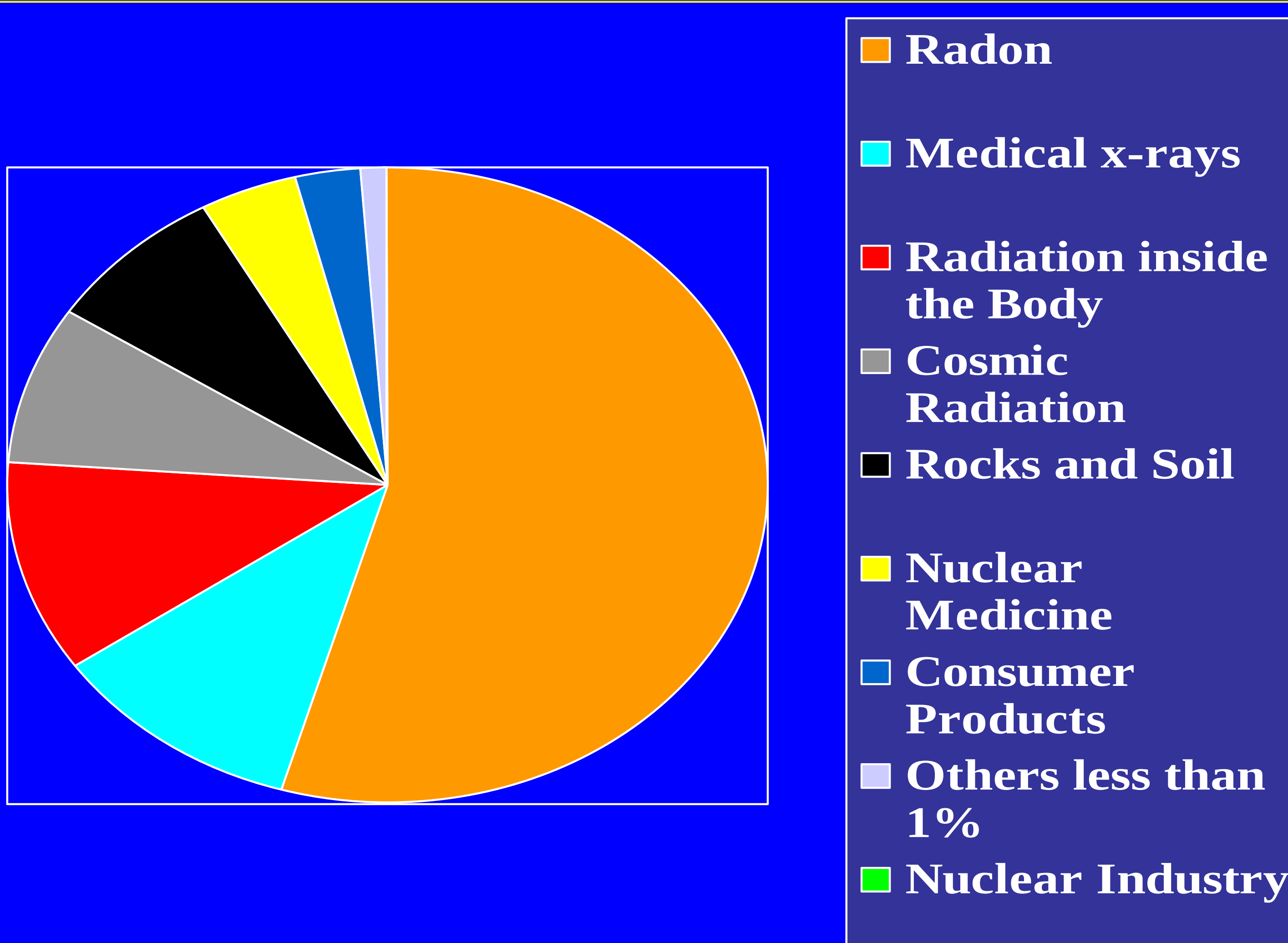


Sources and Amounts Radiation (mR/yr)

Natural Background Radiation

• Radon	200mR
• Cosmic Radiation	27mR
• Internal Radiation from Body	40mR
• Rocks and Soil	28mR
Man-Made Radiation	
• Medical X-rays	39mR
• Nuclear Medicine	14mR
• Consumer Products (TVs, Smoke Detectors, etc.)	10mR
• Other	2mR
Total	**360mR**

Sources of Radiation Exposure



Reference: National Council of Radiation Protection

Typical Medical Doses of Radiation*

* Effective doses , vary depending on equipment, operator, etc.

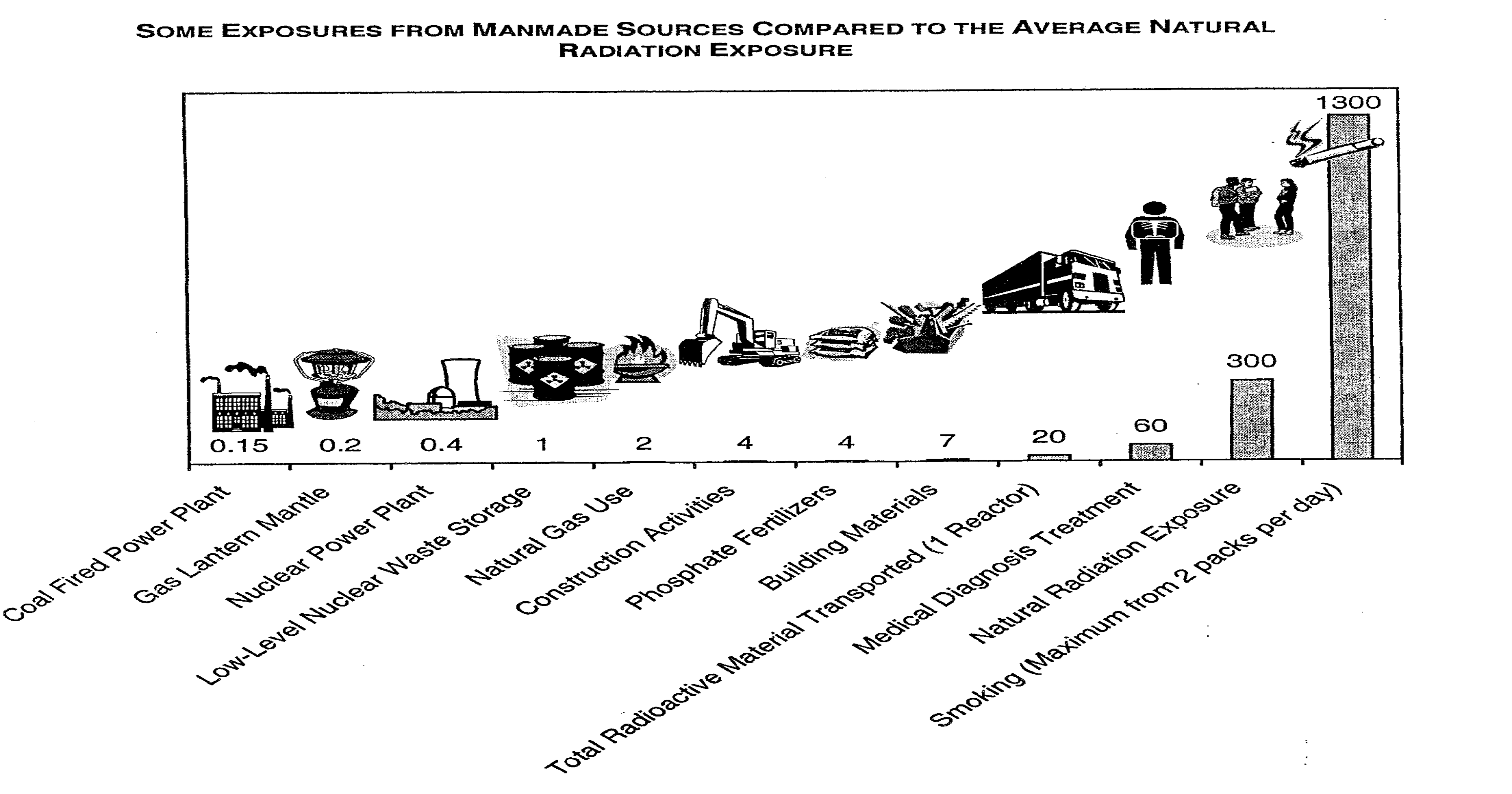
• Chest Study	10 mrem
• Cervical Spine	11 mrem
• Pelvis	27 mrem
• Skull	31 mrem
• Upper GI	117 mrem
• Barium Enema	298 mrem
• CAT Scan	1800 mrem

Environmental Radiation Doses

- Natural background **(Ave annual US, w/o radon)** 100 mrem
- Radon inhalation **(Average annual US)** 200 mrem
- Living within 50 miles of a NPP (annual) <1 mrem
- Television viewing (annual) 1 mrem
- TMI **(average public exposure 50-mile EPZ)** 2 mrem
  - **(average public exposure within 5 miles)** 9 to 25 mrem
  - **(maximum public exposure within 5 miles)** 170 mrem
- Air flight: New York-Los Angeles (per flt) 4 mrem
- Chernobyl **(average public exposure 18 mi)** 1500 mrem
- Radiation Workers - NC Annual limit 5000 mrem
- Public Exposure- Annual limit 100 mrem

SOURCES OF RADIATION EXPOSURE

Exposures from Man-made Sources compared to Average Natural Radiation Exposure (mRems/year)



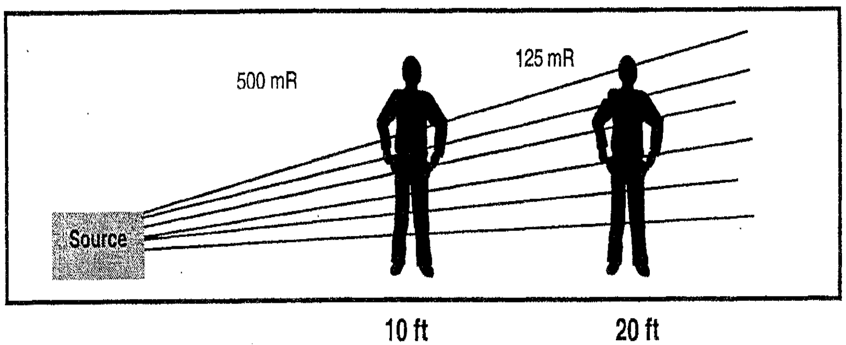
Radiation Protection Methods

Time as Protection Method

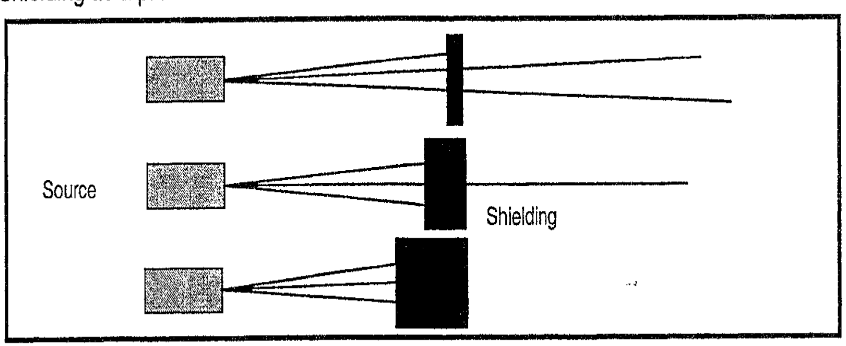
Source: 500 mR/h

Time of Exposure	Dose Received
15 minutes	125 mR
30 minutes	250 mR
45 minutes	375 mR
60 minutes	500 mR

Distance as a protection method



Shielding as a protection method



- **Time**-Limit total exposure by limiting time spent in a radiation environment
- **Distance**-Increase distance from point source, decrease exposure rate by the inverse square law.
- **Shielding**- Use of mass to absorb or scatter beta and gamma radiation
- **Quantity**- Limit the amount of radioactive material in the working area

EMERGENCY WORKER EXPOSURE CONTROL

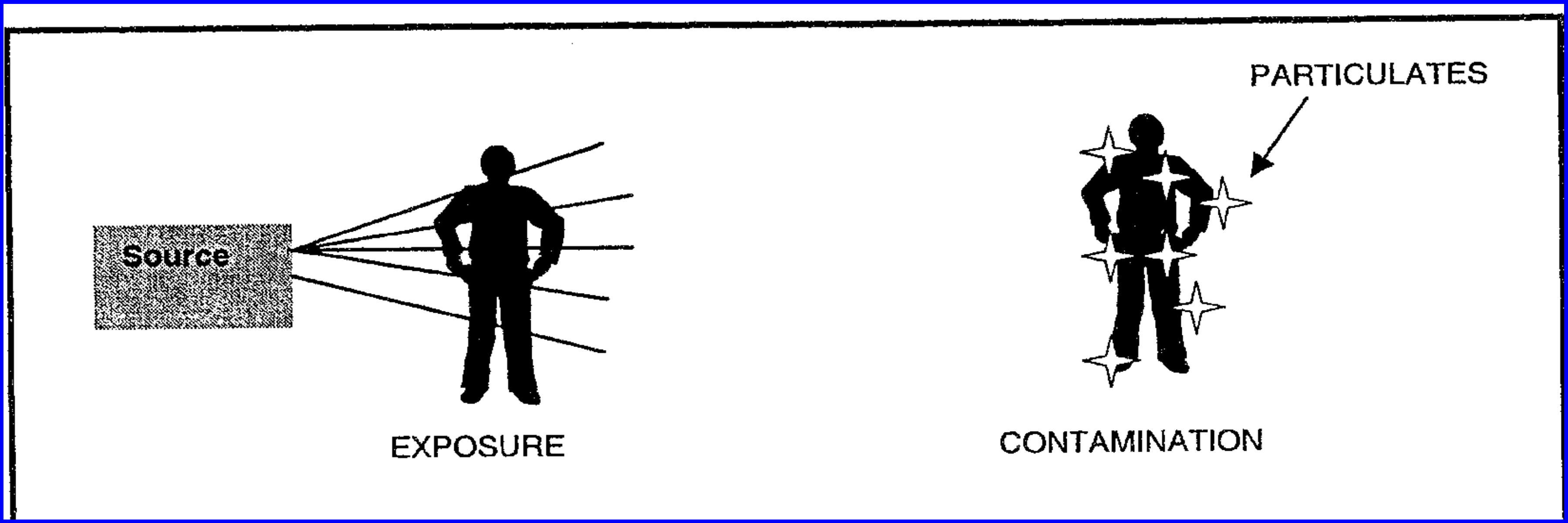
DOSE LIMIT (in rems) **EPA 400-R-92-001**	**EMERGENCY ACTIVITY**	**ACTIVITY CONDITION**
5	All	Use ALARA
10	Protecting valuable property	Lower doses not practical
25	Life saving or population protection	Lower doses not practical
>25	SAME	Only on a fully informed voluntary basis

DOSE LIMIT(in rems) **STATE OF NC POLICY**		
1	Administrative, all activities	Report to supervisor
5	Turn-back value	Report to supervisor
Incident dependent	Mission dose	Limit given by state

EXPOSURE VERSUS CONTAMINATION

EXPOSURE-The amount of radiation a person receives from a source. When associated with time, it becomes the "exposure rate". When a radiation source is eliminated or a person is removed from a radiation environment, exposure ceases

CONTAMINATION-Radioactive particulates deposited on the ground, on individuals or objects. These emit radiation and present an exposure hazard until removed



Radiation Damage

- Occurs at the cellular level
- Initial deposition of energy occurs quickly at 10^{-17} seconds
- Damage results from ionization of critical parts of the cell (DNA), or most commonly from the formation of free radicals that can cause damage within the cell
- Visible damage in cells, tissues and organs cannot be distinguished from other types of trauma

Biological Damage due to Radiation is Determined by Five Factors

- **Amount of Exposure**
- **Duration of Exposure**
- **Type of Radiation**
- **Biological Variability Factors**
  - Age, Sex, Health, Size, Weight, Genetics, etc
- **Portion of Body Exposed**

Biological Effects of Ionizing Radiation

- **Early (Acute)**
  - Symptoms occur in hours to days after exposure
- **Late (Chronic)**
  - Symptoms show up years after exposure
  - Include cancers, leukemia, cataracts, genetic effects

Acute Effects of Radiation*

(Linnemann, 2001)

* Brief Exposure (minutes to a few hours) Whole Body

• No observable effects	5 rem
• Blood abnormalities	15 rem
• Sperm abnormalities	15 rem
• Nausea/Anorexia	100 rem
• Bone Marrow Depression	200 rem
• Epilation	300 rem
• Erythema	600 rem

Dose-Effect after Acute Whole Body Radiation from Gamma or X-Rays Gusev et al

• 5 rem	No symptoms
• 15 rem	No symptoms, possible chromosomal aberrations in cultured peripheral lymphocytes
• 100 rem	Nausea and vomiting in 10% of pts 48 hrs p exp
• 200 rem	Nausea and vomiting in 50% of pts 24 hrs p exp Marked decreases in WBC and platelets
• 400 rem	Nausea and vomiting in 40% of pts 12 hrs p exposure Diarrhea in 10% within 8 hrs, 50% mortality
• 600 rem	100 % mortality within 30 days p exp due to bone bone marrow failure without medical treatment
• 1000 rem	Approximate dose survivable with best medical Tx
• 1000 to 3000 rem	Nausea and vomiting in 100% w/in 5 minutes; Severe GI damage, death 2-3 wks
• 3000 rem	CVS collapse, CNS damage, death 24 to72 hrs

Long Term Effects of Radiation[1]

(Linnemann, 2001)

[1] Brief Exposure (minutes to hours)

• Fetal Abnormalities *	10 rem
• Cancer *	10 rem
• Genetic	250 rem
• Cancer Death Risk 5%	100 rem
• Genetic Risk 1%	100 rem
• Cataracts 10 % **	100 rem

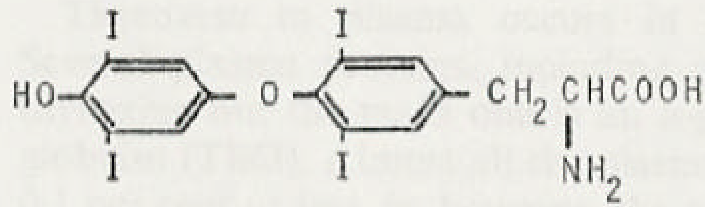
* Levels below which it is difficult to consistently demonstrate effects

** 10 % develop cataracts at this dose of gamma, x-ray

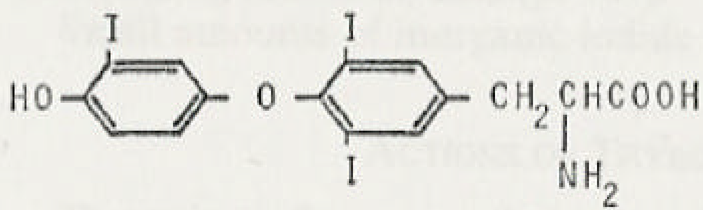
Biosynthesis of Thyroid Hormones

- Iodide in diet absorbed rapidly in small bowel
- 1/3 taken up by thyroid; 2/3 excreted via kidneys
- Thyroid iodide rapidly converted to iodine
- Thyroid iodine concentration is 20x plasma concentration
- May exceed plasma concentration by 100 fold
- Thyroid iodine converted to mono-iodotyrosine and di-iodotyrosine (MIT and DIT)
- MIT and DIT couple to form thyroxin (T_4) (2 moles of DIT) and tri-iodothyronine (T_3) (one mole each of DIT and MIT)
- T_3 and T_4 are incorporated into thyroglobulin which is the main component of colloid in the thyroid follicle

Chemical Structure of Thyroid Hormones



Thyroxine (T_4)



Triiodothyronine (T_3)

FIG. 10.—Chemical structure of the thyroid hormones.

Release of T3 and T4 occurs by breakdown of thyroglobulin by proteolytic enzymes. 90% circulating is T4; 10% is T3

2002 Thyroid Cancer Statistics

Based on incidence rates from the NCI SEER program

- 2 % of all new cancer cases in the U.S.
- Approximately 21,700 new cases each year
  - 4900 in males
  - 15,800 in females
- Treatment via surgery and I-131 is usually effective
- Mortality rate is 6% - approximately 1300 deaths each year.

Three Important Historical Events Related to Radiation-induced Thyroid Disease

- **Discovery of X-rays** (external radiation) and **radioactivity** (internal and external radiation) at the end of the 19th century followed by almost world-wide medical applications
- **Discovery of nuclear fission** in 1939 followed by **atomic bomb explosions** in 1945 and later by **atmospheric tests.**
- **Production of radioactive iodine** in 1942 followed by the **manufacture and widespread use** of iodine-131 in 1946.

C. Silverman MD, DrPH Public Health Reports 1984

The Fourth Important Historical Event Related to Radiation-induced Thyroid Disease

- **Chernobyl Nuclear Power Plant Accident**

Medical Applications- Radiotherapy

1920's to 1950's - common medical practice to use ionizing radiation to treat a variety of benign non-thyroid conditions of the head, neck and upper thorax of infants and children resulting in direct or scatter radiation exposure to the thyroid

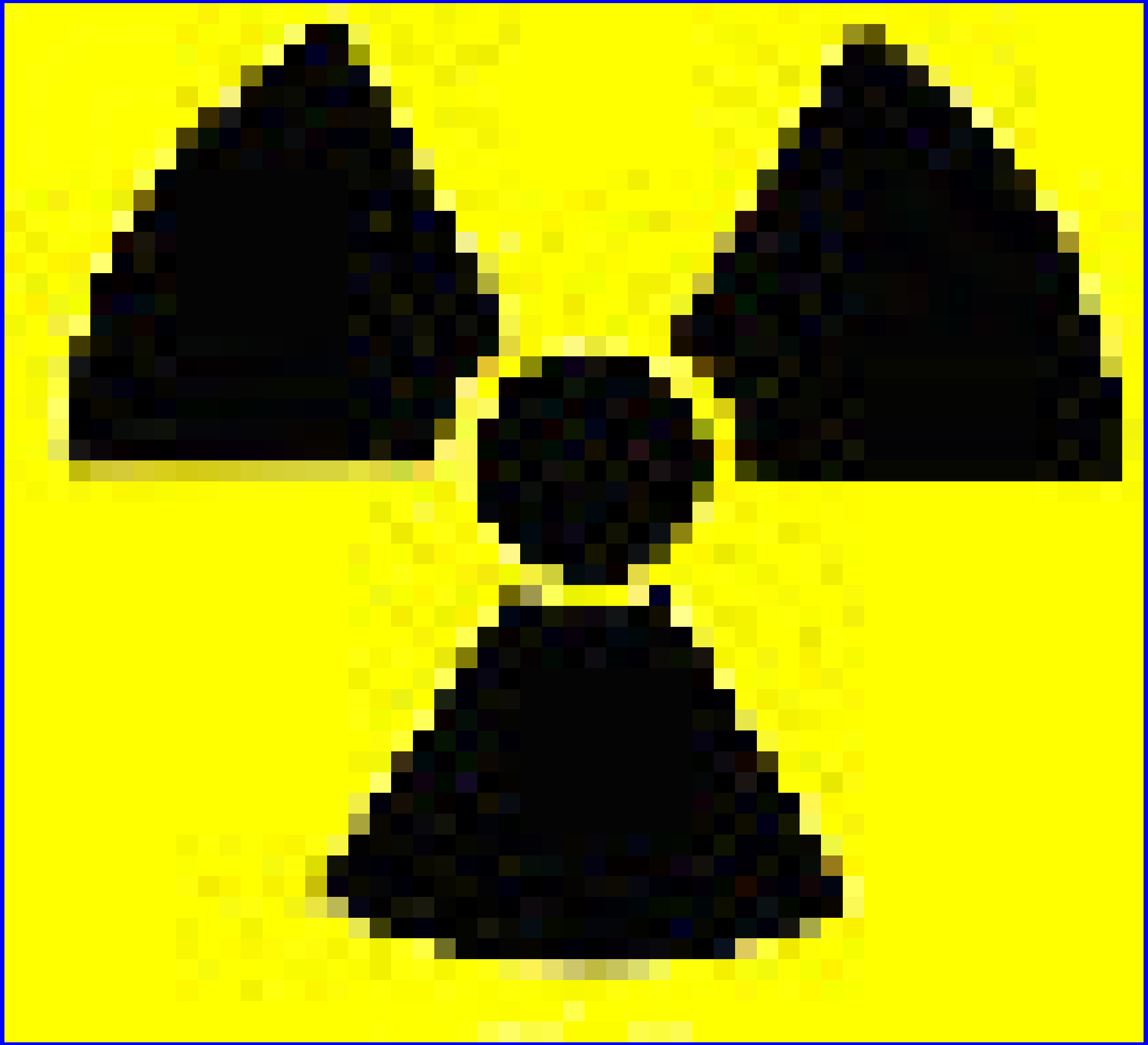
- **Enlarged thymus**
- **Hypertrophic tonsils and adenoids**
- **Cervical adenitis**
- **Ringworm**
- **Acne**

Medical Radiotherapy and Thyroid Cancer

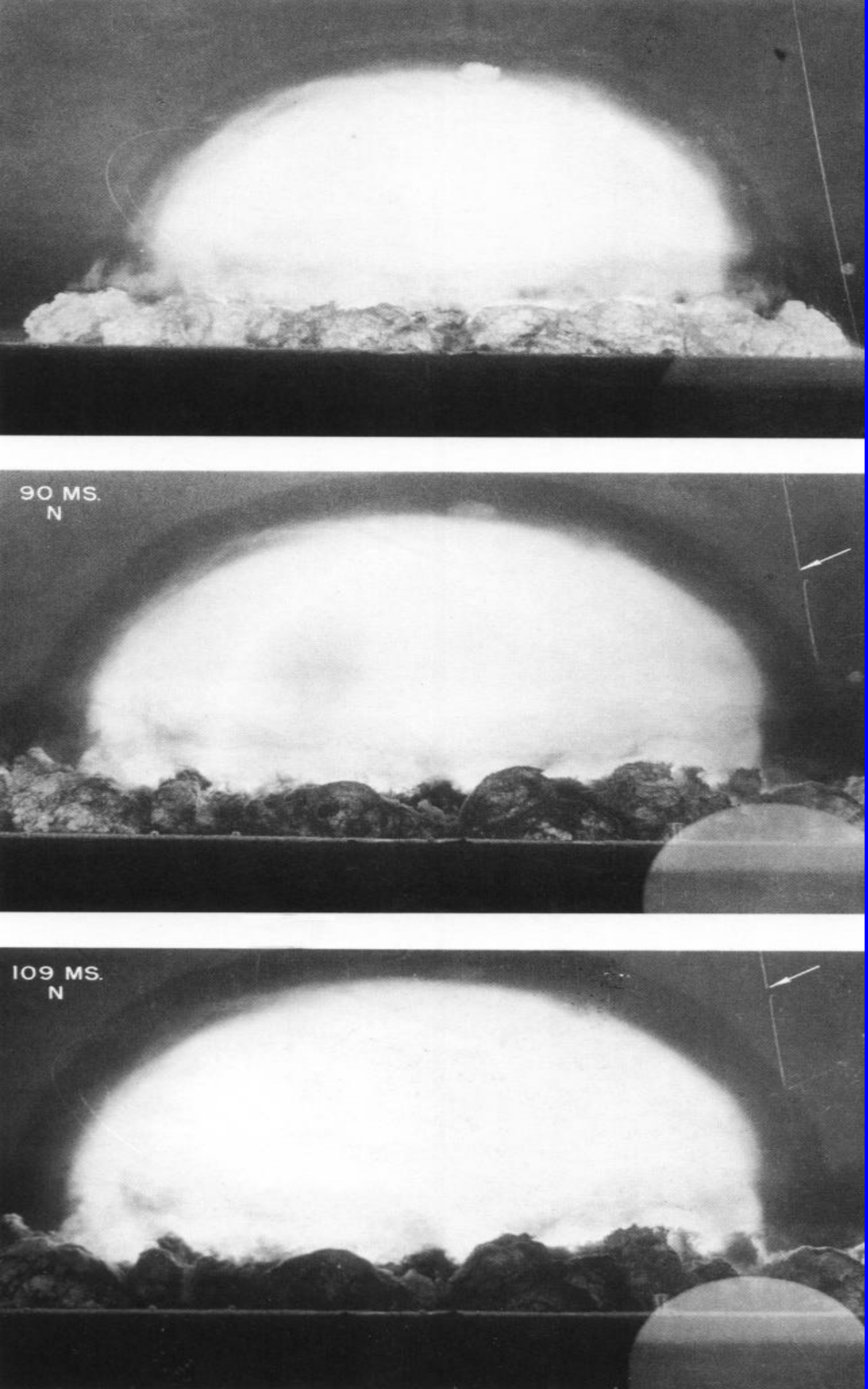
- Duffy et al. Cancer of the Thyroid in Children. J Clin Endocrinology 10:1296-1308 (1950).
  - Case series: Of 28 children and young adults with thyroid cancer,10 had Hx of treatment with X-rays for thymic enlargement 4-19 years earlier when < 18 months old.
- Simpson et al. Neoplasia in Children Treated with X-rays in Infancy for Thymic Enlargement. Radiology 64: 840-845 (1955).
  - Retrospective cohort study: Compared 1400 children treated between 1926-1951 with 1,795 untreated siblings and with the general population of New York and found a significant increased risk in the treated group

Nuclear Testing-USA
July 16, 1945-September 23, 1992

- US conducted 2 nuclear attacks (Japan) and 1054 nuclear tests in the continental US and the Pacific
- Continental testing released about 150 million curies of radioactive iodine into the atmosphere.
- NCI estimates that the average American alive at the time of atmospheric testing received thyroid radiation exposure of 2 rads from I^{131}.
- An estimated 120,000 cases of thyroid cancer with 6000 deaths resulted from these exposures



Trefoil



First Nuclear Explosion

TRINITY

16 July 1945

Alamogordo Test Range

Jornada del Muerto

"Journey of Death" Desert

Robert Oppenheimer, an avid reader of Sanskrit literature, is felt to have provided the test name, which refers to the divine Hindu trinity of:

Brahma (the Creator),
Vishnu (the Preserver), and
Shiva (the Destroyer)


Hiroshima Bombing
August 6, 1945

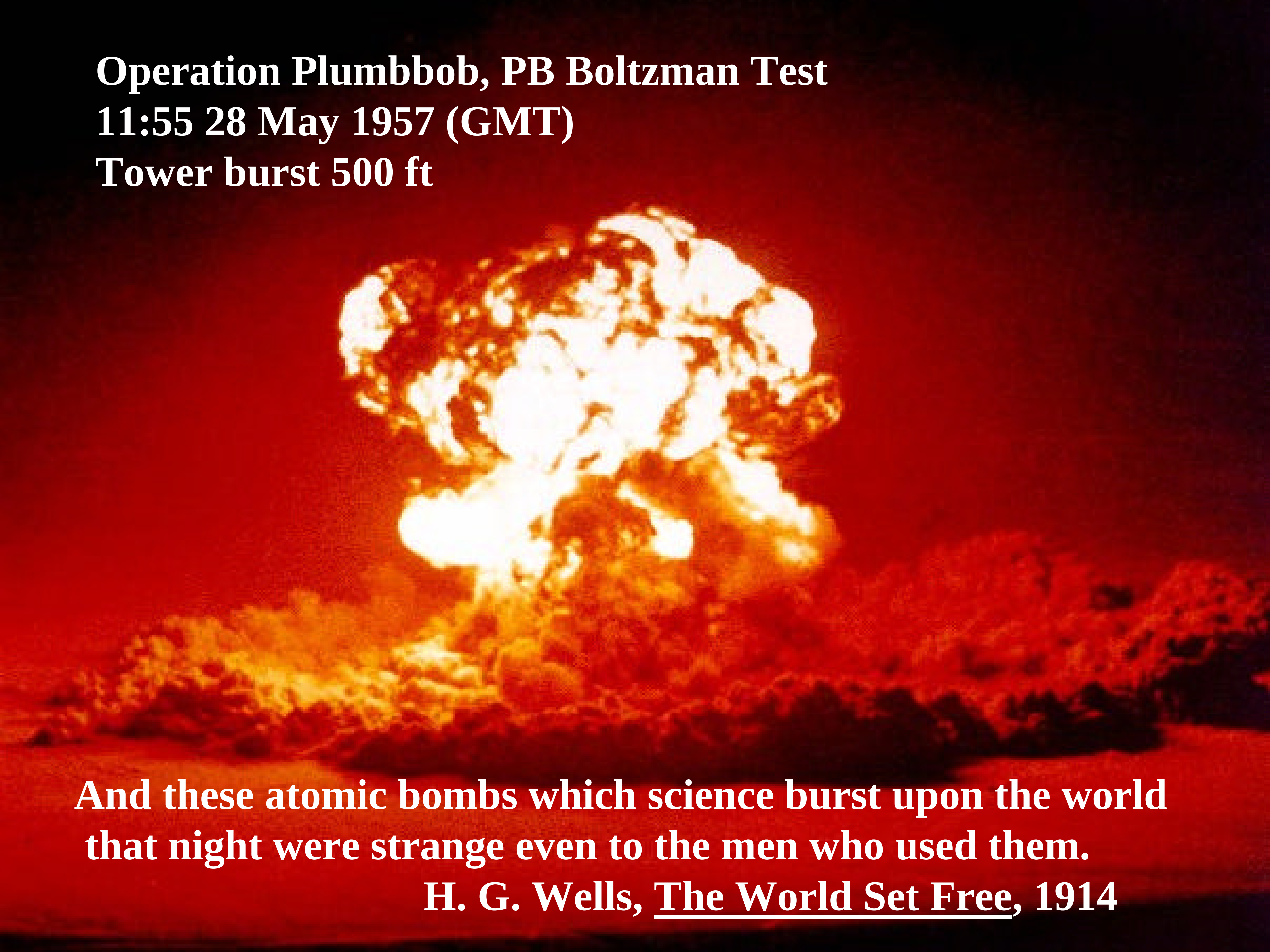
Nagasaki Bombing Survivors

Minimum Exposure ??

Hair loss suggests these children were exposed to at least 300 rem.

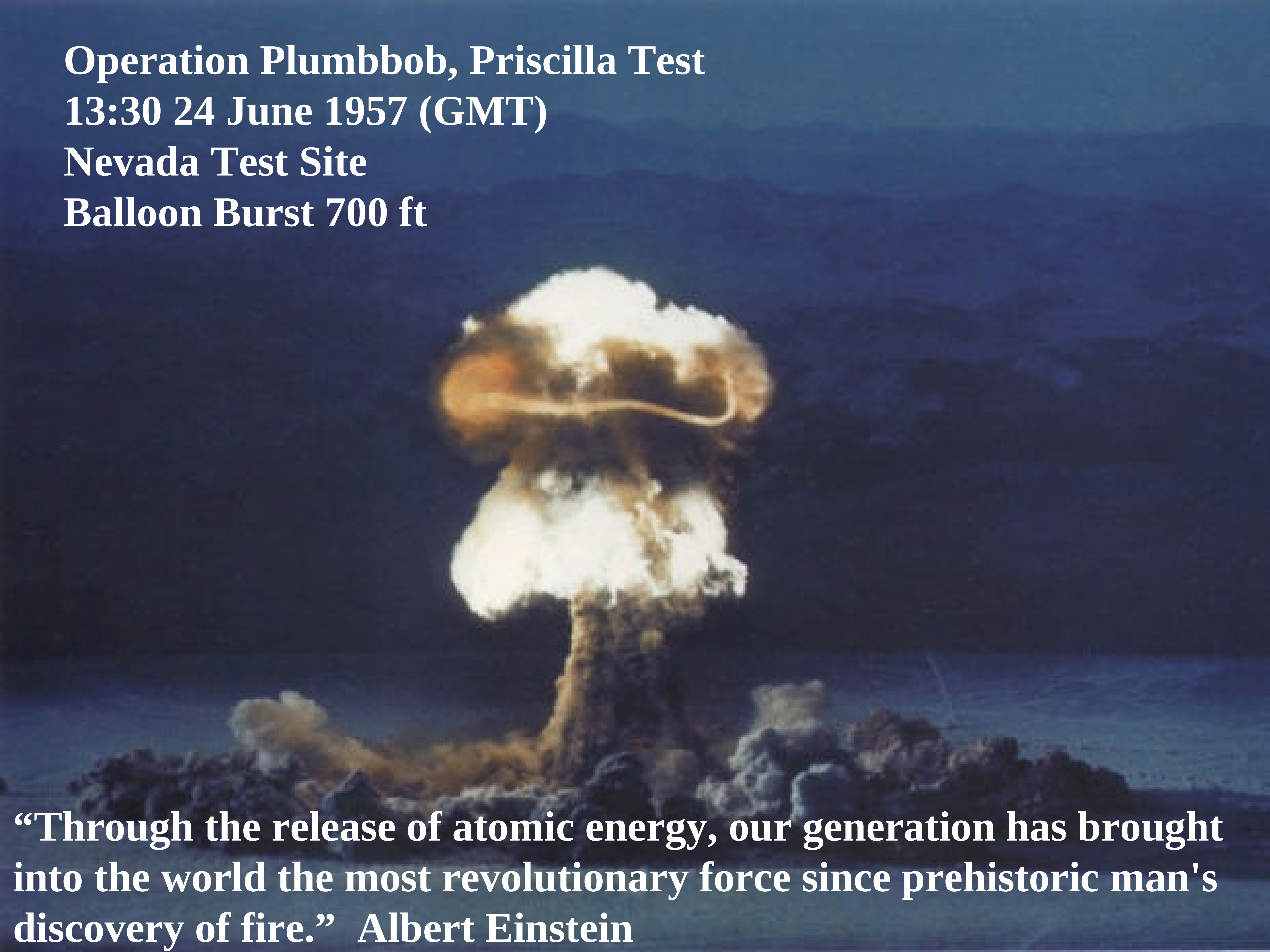

Operation Buster Jangle
Buster Dog Test
Nevada Test Site
15:30 01 Nov 1951 (GMT)
Airburst / No local fallout
Troops 6 mi from ground 0

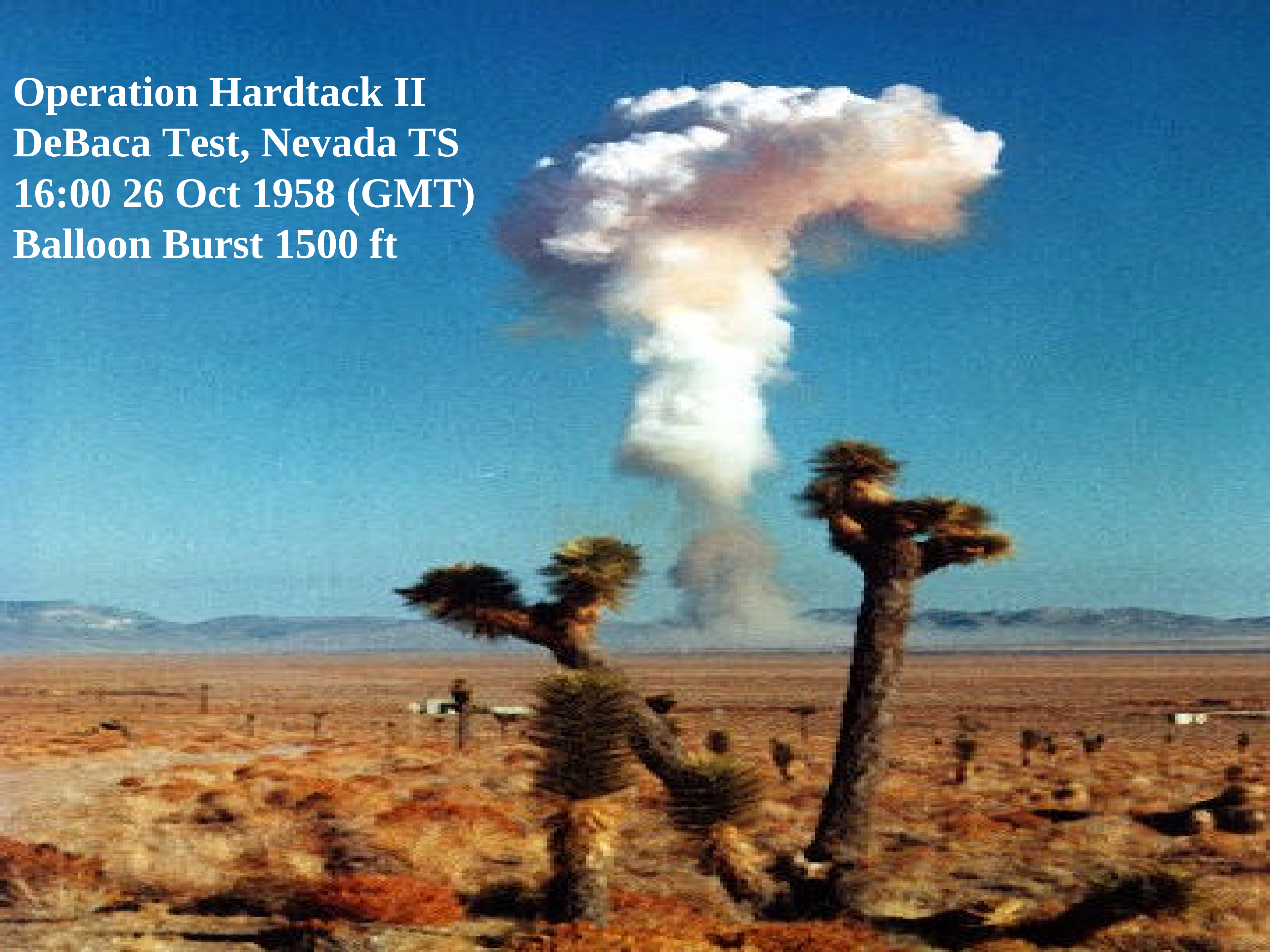
Operation Plumbbob, PB Boltzman Test
11:55 28 May 1957 (GMT)
Tower burst 500 ft



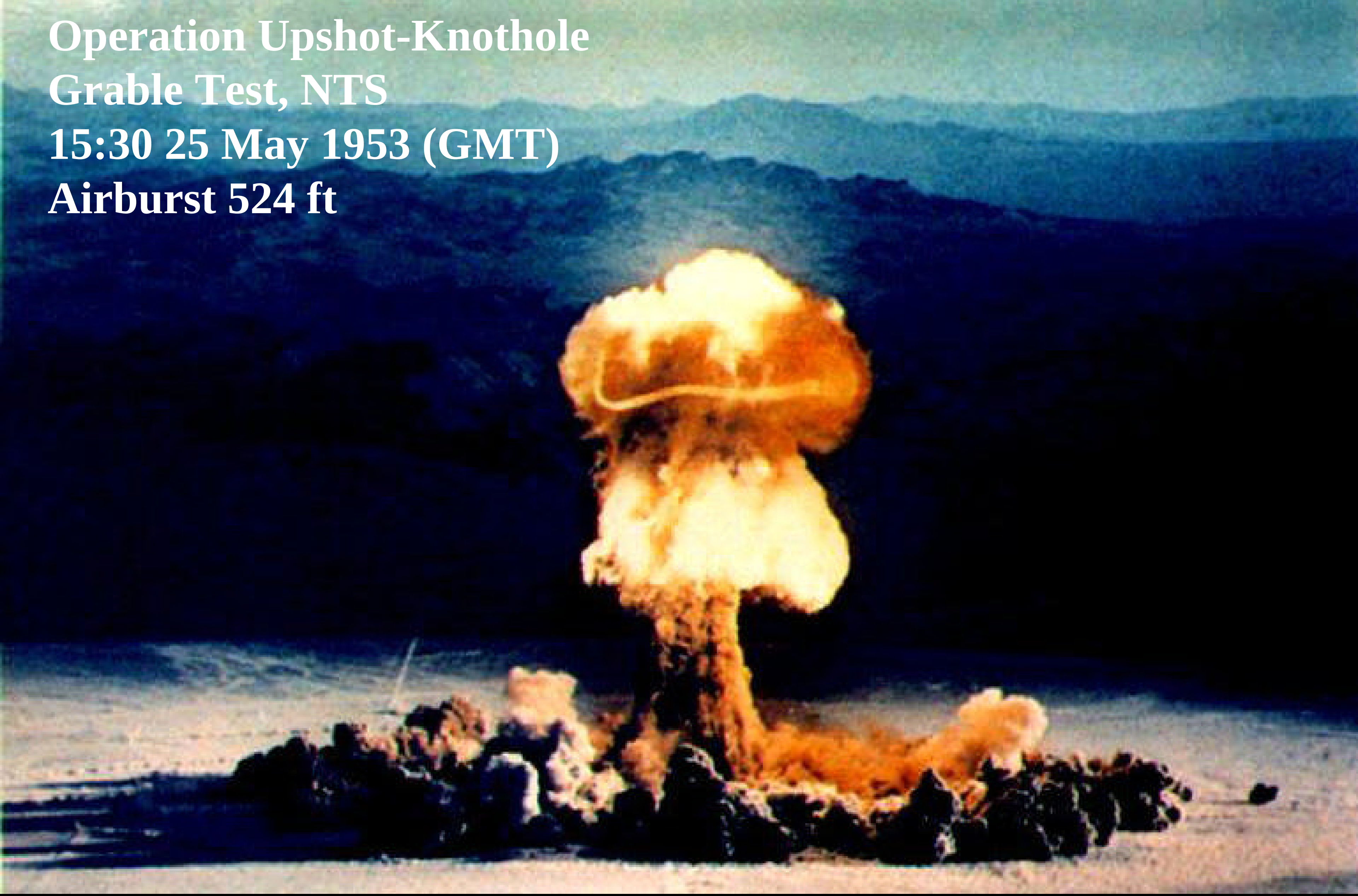
And these atomic bombs which science burst upon the world that night were strange even to the men who used them.

H. G. Wells, The World Set Free, 1914


Operation Plumbbob, Priscilla Test
13:30 24 June 1957 (GMT)
Nevada Test Site
Balloon Burst 700 ft
“Through the release of atomic energy, our generation has brought into the world the most revolutionary force since prehistoric man's discovery of fire.” Albert Einstein


Operation Hardtack II
DeBaca Test, Nevada TS
16:00 26 Oct 1958 (GMT)
Balloon Burst 1500 ft

Operation Upshot-Knothole
Test Badger, Nevada Test Site
12:35 18 April 1953 (GMT)
Tower Burst 300 ft



“I do not know with what weapons World War 3 will be fought, but World War 4 will be fought with sticks and stones.” A. Einstein

Atmospheric Testing (NTS) Radioactive Fallout and Thyroid Cancer

- 1954-Radioiodine found in thyroid glands of dairy cattle near the Nevada nuclear test site (NTS)
- 1968- Hanson et al. Contamination of soft tissues of infants and children with radioactive fallout as exemplified by Cs-137 and I-131. Pediatrics (supp.) 41 (Pt II): 240-256 (1968)
  - Milk identified as the principal source of I-131
  - Children identified as the critical population-at-risk
- Cohort study of children (UT, NV, AZ) begun in 1964 inconclusive

Radioactive Fallout and Thyroid Cancer

- Rallison et al. (1990, Health Physics)
  Examined cohort of children (11-18 yrs) born between 1947-1954 in two counties (UT/NV) near the NTS for thyroid abnormalities and compared to a control group from a county in AZ presumed to have received little / no fallout.
  - **1965-1968 4819 individuals examined**
  - **Thyroid nodules found in 76 of 4819 children examined; 22 were neoplasms**
  - **UT/NV rate 5.6/1000 AZ rate 3.3/1000 RR=1.7 not significant**
  - **1985-86, 3122 of the original study subjects reexamined**
  - **Thyroid nodules found in 125; 65 were neoplasms**
  - **UT/NV rate 24.6/1000 AZ rate 20.2/1000 RR = 1.2 (p=0.65)**
  - **Kerber et al. (1993, JAMA) Reanalysis based on level of estimated exposure suggests RR of 3.4 for exposures >400 mGy**

National Cancer Institute Study Estimating Thyroid Doses of I-131 Received by Americans From Nevada Atmospheric Bomb Tests (October 1, 1997)

- 90 nuclear tests in the years 1952, 1953, 1955, and 1957 released est 150 million curies of I-131 into the atmosphere
- Lowest deposits on west coast, upwind of the NTS
- In eastern US, most deposition associated with rain
- In the more arid west, mostly dry particle deposition
- Exposure occurred primarily during 60 days following a test due to 8-day half life of I-131
- Average thyroid dose to 160 million persons was 2 rads with a per capita uncertainty factor of 2
- Large variations in thyroid dose based on county of residence, age at time of exposure and milk consumption

Thyroid Cancer and Atmospheric Testing

- Children exposed to radioactive fallout from nuclear explosions in the 1950s may be at risk
- Scientists do not have a reliable way to estimate the risk of thyroid cancer from radioactive fallout
- Thus far, studies of exposure to radioactive iodine (I-131) for medical purposes or from fallout in areas close to the site of atomic bomb tests in the 1950s have produced no conclusive evidence that such exposure to I-131 is linked to cancer.

NCI: August 1, 1997

Estimated Lifetime Risk of Radiation-Related Thyroid Cancer in the U.S. Population from the NTS Fallout

- 49,000 lifetime excess cases (95% confidence limits 11,300-212,000)
- Assumes 2 rads per capita exposure
- Dose-specific excess risk is based on studies of Hiroshima and Nagasaki survivors and medically-exposed populations
- Considers relative risk is inversely related to age at exposure
- Assumes risk post-exposure is constant over the remainder of life
- Assumes an RBE of 0.66 for inhaled/ingested I-131 compared to x-ray and other gamma ray exposure

Charles Land presentation NAS/IOM meeting December 19, 1997

"If used in numbers, atomic bombs not only can nullify any nation's military effort, but can demolish its social and economic structure and prevent their re-establishment for long periods of time.

With such weapons, especially if employed in conjunction with other weapons of mass destruction such as pathogenic bacteria, it is quite possible to depopulate vast areas of the earth's surface, leaving only vestigial remnants of man's material works."

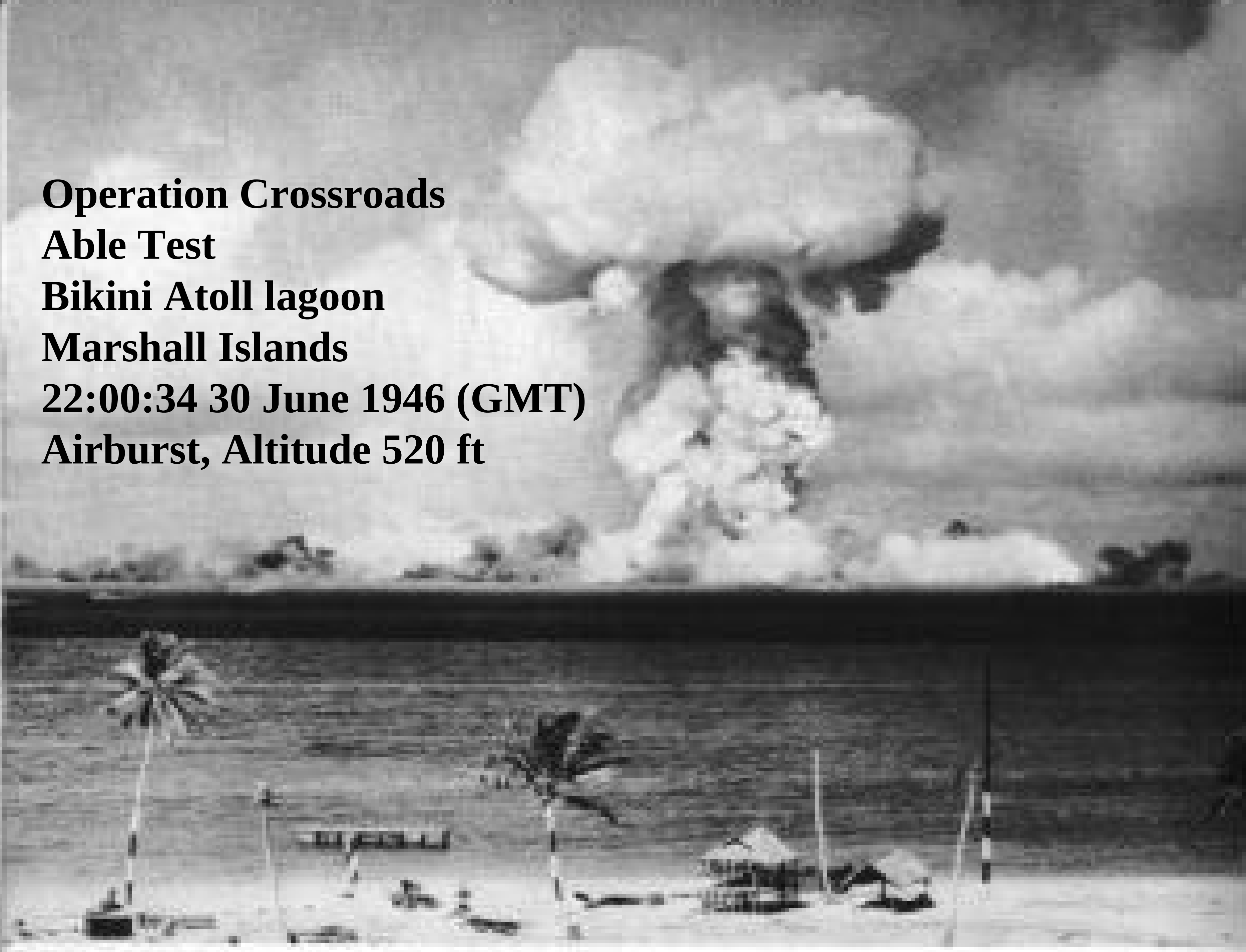
Albert Einstein

Report of the Joint Chiefs of Staff

Operation Crossroads

June 30, 1947

Operation Crossroads
Able Test
Bikini Atoll lagoon
Marshall Islands
22:00:34 30 June 1946 (GMT)
Airburst, Altitude 520 ft




Operation Crossroads - Baker Test
Bikini Atoll lagoon, Marshall Islands
21:35:00 24 July 1946 (GMT)
Subsurface-burst, Depth -90 ft

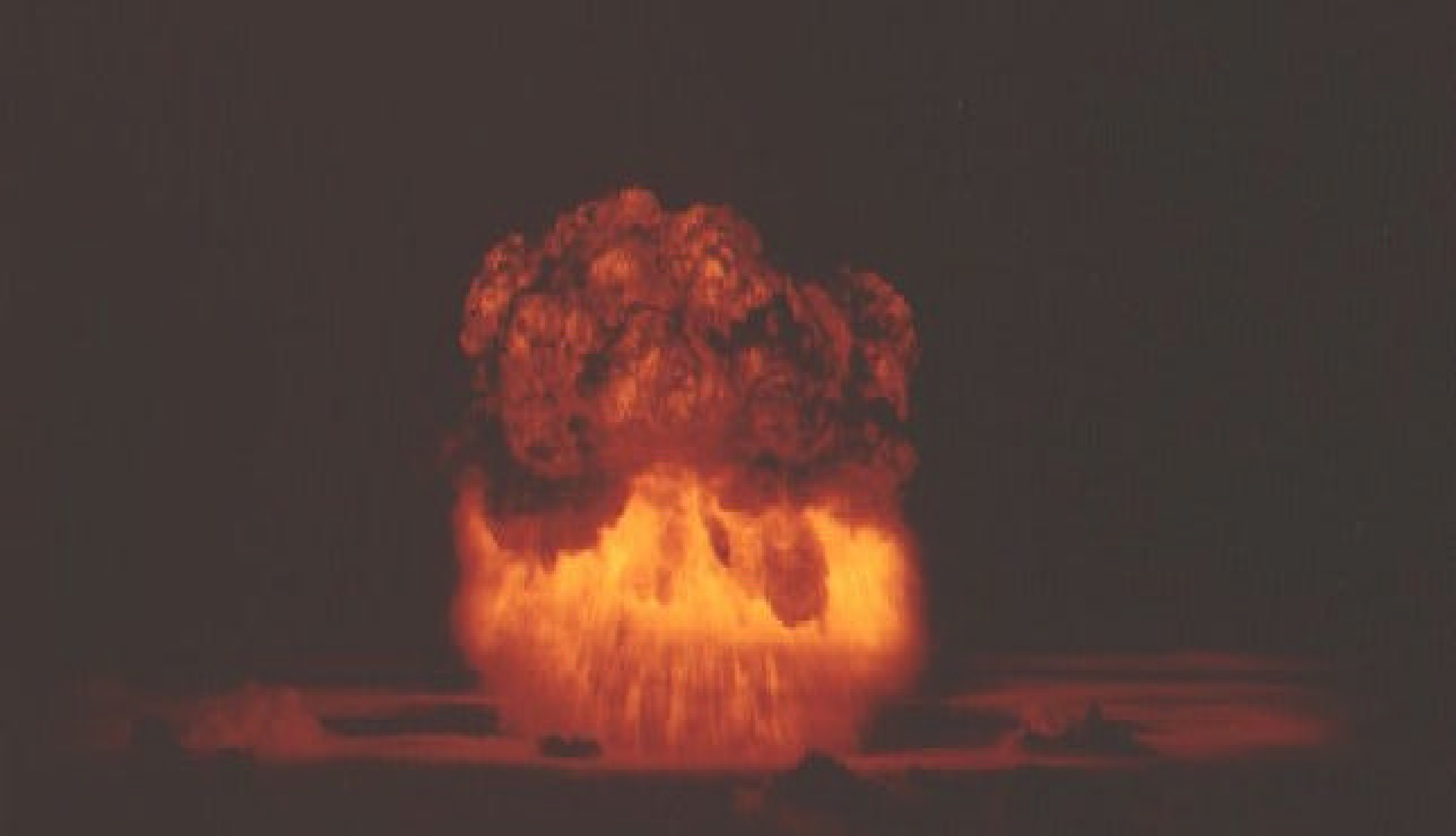

aker Test
ilson Cloud Chamber Effect

Baker subsurface burst
Cloud stem

Operation Greenhouse, Test George Island Enjebi, Enewetok Atoll
18:26:20 April 1951 (GMT)

Operation Ivy, Mike Test, First Hydrogen Bomb Test, Surface Burst Elugelab Island, Enewetak Atoll 19:14:59 31 Oct 1952 (GMT)

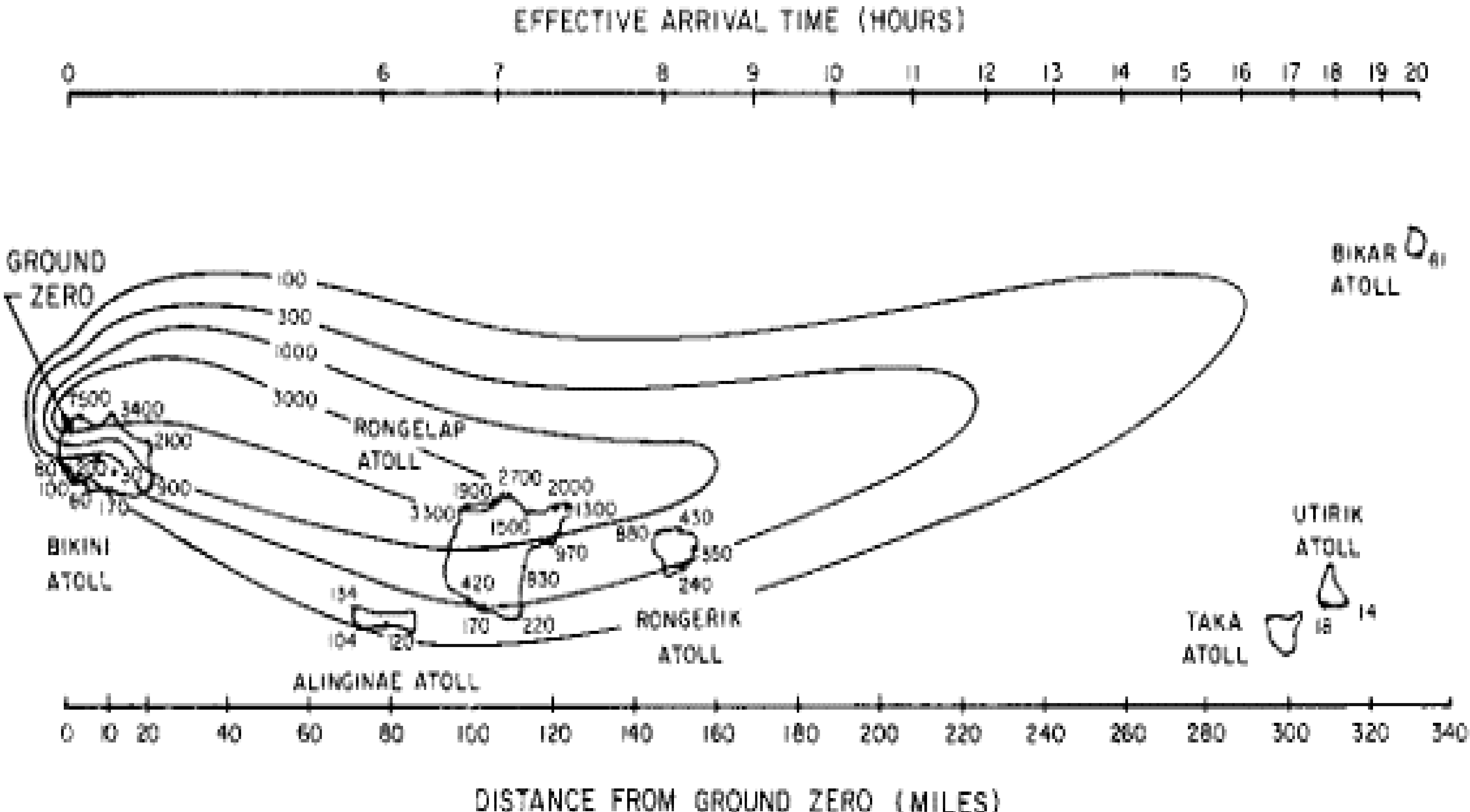

Operation Ivy, Test King, Runit Island, Enewetak Atoll
23:30 15 November 1952 (GMT) Airburst 1480 ft



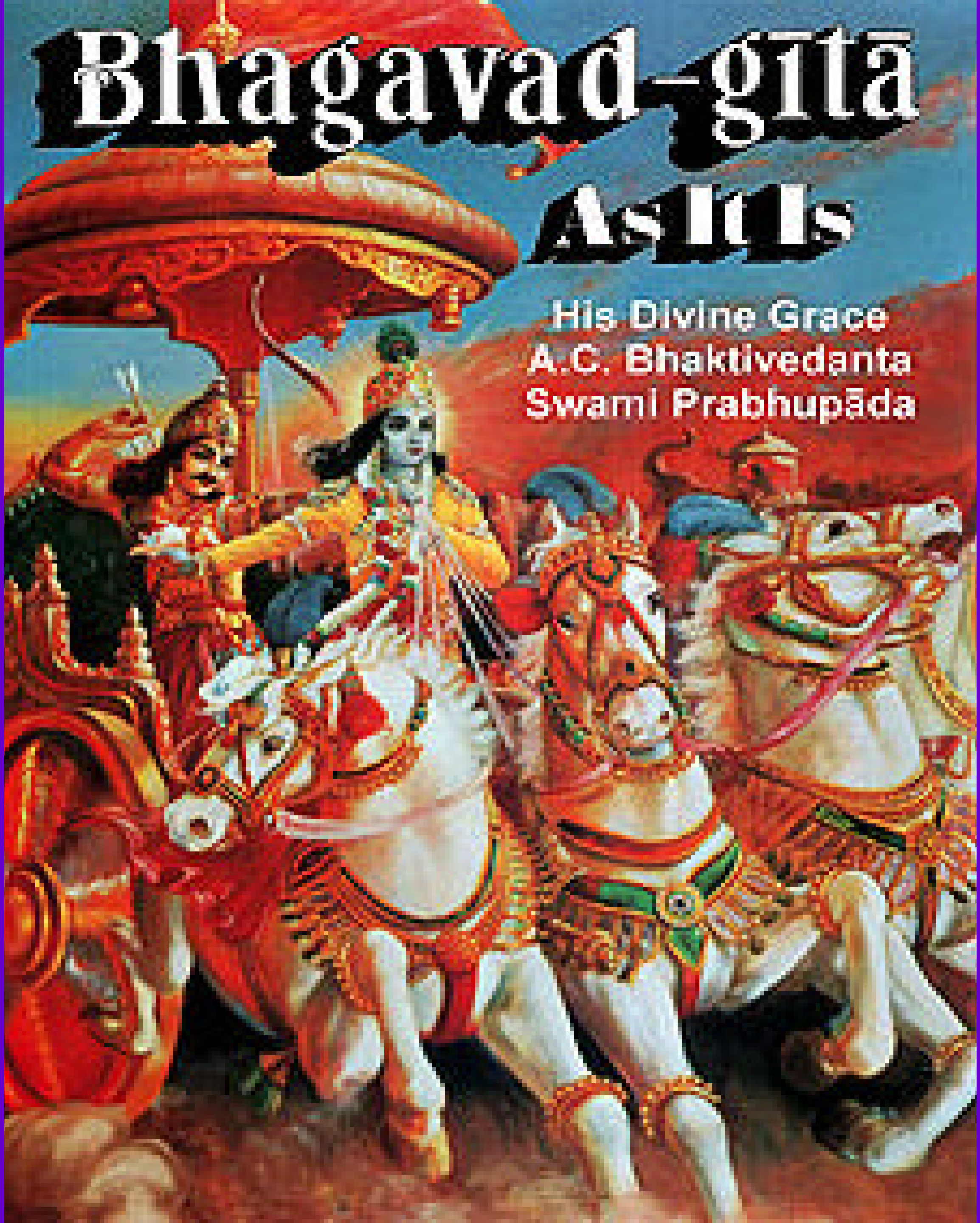
Operation Castle, Bravo Test, off Nam Island, Bikini Atoll
18:45 28 Feb 1954 (GMT)
Test Resulted in the Worst Radiological Disaster in US History
Marshallese Islanders were blanketed with fallout from the plume

Operation Castle, Bravo Test, off Nam Island, Bikini Atoll
18:45 28 Feb 1954 (GMT) Artificial island reef
Surface burst 7 ft
Crater 6510 ft wide, 250 ft deep

Contour lines showing cumulative radiation dose in Roentgens in the first 96 hours following the Castle Bravo Test.




Operation Redwing
Enewetok and Bikini Atolls
!956


Bhagavad-gītā
As It Is
His Divine Grace
A.C. Bhaktivedanta
Swami Prabhupāda


If the radiance of a thousand suns
Were to burst at once into the sky,
That would be like the splendor of the Mighty One...
I then become Death,
The shatterer of Worlds.
The Bhagavad-Gita
15th century Sanskrit religious text
Redwing Dakota Test 18: 06 June 1956 (GMT)
Barge Shot off Yurochi Island, Bikini Atoll

Operation Umbrella, Hardtack Test, 23:15 8 June 1958 (GMT)
Enewetak Lagoon, Underwater Burst -150 ft

Operation Hardtack, Oak Test
19:30 28 June 1958 (GMT)
Enewetak Lagoon, Barge Shot 8.6 ft

Operation Dominic, Frigate Bird Test
23:30 6 May 1962 (GMT), Johnston Island
Airburst, 11, 000 ft Polaris Missile launch
Periscope view from USS Carbonero 30 mi.

Operation Dominic

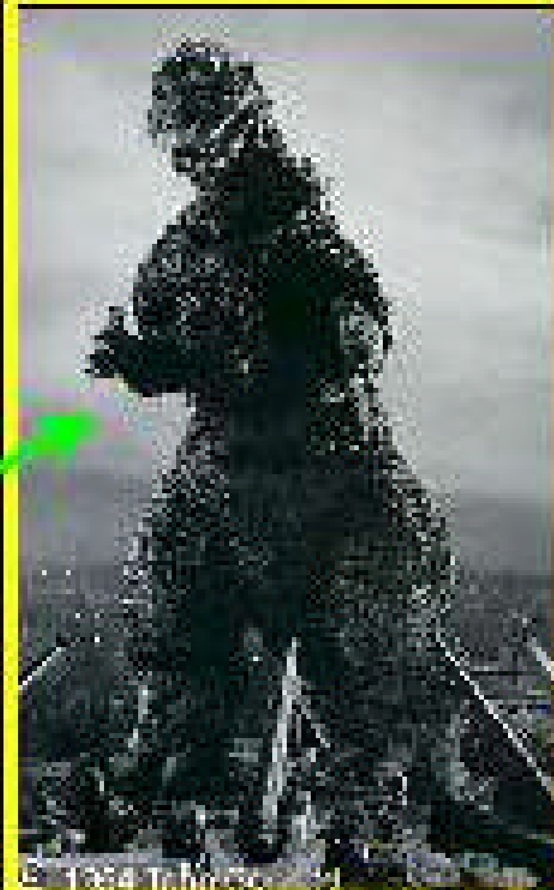
Truckee Test

15:37 9 June 1962 GMT

10 mile S of Christmas Is

B-52 Airdrop Burst

6970 feet



Godzilla

?????????

Pituitary Effects of Nuclear Testing in the South Pacific

During WW2 Japan pictured America (FDR) as a monster demon. Couple this with the atomic destruction of Japanese cities by America and Godzilla is born in the 1950s.

Radioactive Fallout and Thyroid Cancer

- **Atomic Bomb Casualty Commission Studies**
  Survivors of 1945 bombings of Hiroshima and Nagasaki
  - 16 years post detonation, excess of thyroid tumors first noted
  - 26 years pd, the excess was statistically significant
- **Marshall Islanders**

  1964-Thyroid nodules begin to appear in Marshallese accidentally exposed to fallout in 1954
- **Chernobyl NPP accident-**1986-new data

September 23, 1996

US and other nuclear powers sign the
Comprehensive Test Ban Treaty

Legal commitment to never test nuclear devices again

Most Sensitive Population to Thyroid Irradiation?

Children

Children’s Thyroids

- Are more sensitive to the carcinogenic effects of ionizing radiation based on studies involving external irradiation
- Receive higher doses from ingested or inhaled I-131 than do the glands of adults because of:
  - smaller gland size
  - higher intake of milk
  - higher metabolism

Childhood Exposure and Thyroid Neoplasia (M/B)

- +/+ Hempleman, LH et al. (JNCI 1975) - thymic-irradiated children in Rochester, NY area
- -/+ Pifer, JW et al. (1968) - thymic- irradiated children in Ann Arbor, MI area
- +/+ Ron, E et al. (JNCI 1980;1984) - X-ray epilation for tinea capitis in Israel
- -/+ Shore, RE et al. (Arch Env Health 1976) - X-ray epilation for tinea capitis in NYC (low # Females)
- +/NR Jablon, S et al. (Lancet 1971) - Japanese atomic bomb survivors
- +/+ Conrad, RA. (*In* Radiation-associated Thyroid Carcinoma 1977) - Marshallese study

Childhood Exposure and Thyroid Neoplasia

- Risk of thyroid neoplasia following external X-irradiation of the thyroid has been conclusively demonstrated in epidemiological studies and animal experiments.
- Estimated absolute risks of radiation-induced thyroid malignancy following early exposure range from 2.1- 6.1 cases per million children per rad per year.
- Benign adenomas generally occurred 2 to 3 times as frequently as malignant neoplasms.

Childhood Exposure and Thyroid Neoplasia

Important Radiation Factors:

- **Thyroid Dose**

  Studies over range of 6-1500 rads; some studies show dose/response relationship; Israeli tinea capitis study suggested carcinogenic dose as low as 9 rads)

- **External vs. Internal Radiation** (FDA rat study)

  No difference between I-131 and X-rays in the induction of thyroid cancer over range of radiation from 80 up to 1000 rads; histologic types were papillary and follicular-- similar to those in human studies.

  (Lee,W et al. 1982, Radiation Res.)

Childhood Exposure and Thyroid Neoplasia
Important Host Factors

- **Sex:** Radiation-induced thyroid tumors occur up to 4 times more frequently in females.
- **Age:** Infants and young children are more sensitive RR of exposure in 1st yr of life vs. 10th yr is est at 40
- **Ethnic Background**: Jewish ?? more susceptible
- **Latent Period:** Unrelated to dose. Thyroid Cancer (Pre-Chernobyl: minimal 5-10 yrs; peak 15-25, new cases up to 40 yrs later) Adenomas (minimal 10-15 yrs)
- **Types of Thyroid Disease:** Most radiation-induced thyroid cancers are either papillary, follicular, or mixed. Hypothyroidism and acute thyroiditis are associated with higher doses of radiation.

Three Mile Island

March 28, 1979 TMI Unit 2 experienced a partial core melt due to "human error, insufficient training, bad operating procedures and unforeseen equipment failure."

www.Onlineethics.org/cases/tmi/impact.html

TMI Event/Sequelae

- Reactor Core Meltdown 51%
- 10 million curies of radioactivity released into the atmosphere (Xe, only 18 curies of RAI)
- Reactor vessel relatively undamaged
- Cleanup required 400 workers, 4 1/2 yrs and 970 million $$$
- 74 of 127 NPPs under construction cancelled
- 13 NPPs operating at the time have since closed
- No new NPPs ordered in US since TMI*
- Important Information
- Far easier to have a core meltdown than expected
- Reactor vessel able to withstand much higher temperature than expected

TMI Epidemiologic Studies

- Hatch et al. 1991
  - Hospital-based cancer incidence study comparing pre and post TMI rates
  - Cohort 160,000 persons residing in 10 mile radius (1979-85)
  - Study area 69 study tracts / cancer cases for 1975-85
  - Rates adjusted for population density, income and education but not personal risk factors
  - No association for adult leukemia or childhood cancers
  - Elevated risk for NHL (OR=2.0; 95% CI:1.2-3.5)
  - Elevated risk for Lung CA (OR=1.75; 95% CI: 1.47-2.08)

TMI Epidemiologic Studies (continued)

- Ramaswamy et al. 1991
  - PA Department of Health Cancer Incidence Study
  - Followed original 35,946 TMI Registry Cohort annually from 1982-1988 to determine vital status and cancer diagnoses via the PA Cancer Registry
  - Age-sex adjusted incidence rates for the cohort were compared with corresponding SEER data and data for PA
  - SIRs indicated the six-year CA incidence among those exposed to radiation and psychological stress from the accident were not significantly different from the control populations.
  - Cancer incidence was not related to the level of accident radiation exposure.

TMI Epidemiologic Studies (continued)

- Ramaswamy et al. 1989, PA DoH Mortality Study
  - Used PA Cancer Registry to determine 6 year mortality follow-up for the period 1979-1985
  - Age-adjusted SMRs calculated using PA death rates (excluded Philadelphia) for computing expected deaths
  - Multiple regression analyses performed to determine probabilities of death from all causes, non-CA and CA in relation to radiation dose estimates 10 days post accident
  - No association between estimated likely or maximum gamma exposure and all cause, non-CA or CA mortality
  - Controlled for age, race, sex, pre-TMI: CA Dx, thyroid disease Dx, radiation Tx and occupational radiation exp.

Talbott et al. Long Term Follow-up of the Residents of the Three Mile Island Accident Area: 1979-1998. Env Health Perspectives Online 30 October 2002.

- **Cohort Mortality Study initiated by PA Dept of Health**
- **Large Cohort (32,135 residents enrolled in 1979 - 93% of the population residing within 5 miles of TMI)**
- **Long term - 20-year - follow-up (1979-1998)**
- **Overall cancer mortality was similar to the local population SMRs 103.7 (male) and 99.8 (female)**
- **RR modeling-neither maximum gamma, nor likely gamma exposure was a significant predictor of MN, BTL or HD after adjusting for known confounders**
- **RR for max gamma exp in relation to LHT was significantly increased for males, suggestive of dose-response relationship (RR=1.00, 1.08, 1.13, 1.31; SMRs 104.2, 113.2, 117.9)**
- **Upward trend of RRs and SMRs for maximum levels of gamma exp in relation to breast cancer in females (RR=1.00, 1.08, 1.13, 1.31;SMRs=104.2, 113.2, 117.9)**

Long Term Health Effects of TMI

"Although the surveillance within the TMI cohort provides no consistent evidence that radioactivity released during the nuclear accident has had a significant impact on the overall mortality experience of these residents, several elevations persist and certain potential dose-response relationships cannot be definitively excluded."

Talbott et al. , Env Health Perspectives On-line October 2002

The Fourth Important Historical Event Related to Radiation-induced Thyroid Disease

- **Chernobyl Nuclear Power Plant Accident**

Chernobyl Accident/Sequelae

- Worlds worst reactor disaster
- Experiment-water cooling system turned off
- Led to uncontrolled nuclear reaction
- Reactors protective cover blown off by steam explosion
- 100 million curies of radionuclides released into atmosphere
- Plume spread across northern Europe into Great Britain
- 31 people died as a direct result of accident
- 100,000 Soviet citizens evacuated
- Subsequent deaths due to radiation unknown
- Dramatic increase in thyroid malignancy in children 4 years later

Chernobyl Accident - April 26, 1986

Figure 31 Soviet-Designed Nuclear Power Plants

Post-accident Events

- For 10 days following the accident, the population of large parts of Belarus, northern Ukraine and a small part of the Russian Federation were exposed to high levels of fallout.
- Population in general was not immediately informed of the accident
- Some living near the reactor were evacuated starting about 36 hours after the accident
- No effective distribution of stable iodine
- No immediate ban on milk consumption

Chernobyl Nuclear Power Plant Accident-1986-Radioiodine

- Massive quantities of radioiodine released
- Large populations acutely exposed via inhalation and ingestion of cows' milk. About 80% RAI exposure from ingestion and 20% via inhalation
- Direct measurements of thyroid exposure were made in 100,000s of persons exposed
- Most comprehensive and reliable data describing the relationship between radiation dose to the thyroid following environmental release of I^{131} and risk of thyroid cancer

A Red Flag

- First indication of a thyroid disease problem came in 1990
- Increased numbers of thyroid carcinomas were reported in Minsk (capital of Belarus) and Kiev (capital of Ukraine)
- Accuracy of the reports were confirmed by independent evaluation in 1992 **(Kazakov et al; Baverstock et al. Nature 359;21-22, 1992**.

- Total number of cases of thyroid cancer in those exposed as children is now over 2000.
- **(UNSCEAR 2000 Report Vol 2 Annex J)**
- Highest incidence rate is in Gomel Oblast in the south of Belarus; this area received the highest levels of fallout.
- Virtually all of the cases are papillary carcinomas
- Morphology is variable: Early tumors were solid immature tumors with marked local invasion; later tumors more often well-differentiated classical papillary carcinomas
- Estimated total # cases of thyroid cancer from the accident: 4000-6000 resulting in 200-300 deaths

assumes a 5% death rate

Molecular Studies

- RAS and RET are the two main oncogenes involved in thyroid carcinogenesis
- In the Chernobyl cases, point mutations of RAS oncogenes are rare or absent, while rearrangements of the RET oncogene occurs in $\geq$ 50% of tumors

Other Effects

- No reliable evidence of an increase in hypothyroidism
- One study (Yamashita et al) did find increased levels of TSH in the most heavily exposed areas
- Incidence of benign follicular tumors (adenomas) is increasing and may outnumber malignancies.
- May be a delayed increase in follicular thyroid cancer
- Estimated 10,000-20,000 thyroidectomies
  - inadvertant or unavoidable parathyroidectomy
  - trauma to the recurrent laryngeal nerve
  - thyroid replacement hormone
- Genetic effects
- Other malignancy including breast cancer where RAI may play a role

Radioiodine-induced Thyroid Malignancy following Chernobyl

- Approximately 4 years post-accident dramatic increases in the incidence of thyroid cancer among children of Belarus, Ukraine and Russia (areas most impacted by the plume) were observed.
- Incidence of thyroid CA in children 0-4yrs was 30-60 times the pre-accident incidence
- Increased incidence approached 100 x in the most heavily impacted areas; 100 cases in Gomel region vs 1 to 2/yr
- Most cases occurred in children who received < 30cGy to the thyroid
- 75% local lymph node metastasis; 50% poorly differentiated

Prophylaxis with KI in Poland

- Approximately 10.5 million children under 16 y.o. and 7 million adults received at least one dose of KI
- No observed increase in the incidence of thyroid malignancy post-Chernobyl
- Low incidence (1%) of adverse effects (GI distress, bad taste, minor rashes)
- Low incidence (0.37%) of transient hypothyroidism in neonates
- Only 2 allergic reactions observed (both adults with known iodine sensitivity)

Chernobyl: Lessons Learned

- Chernobyl data support the etiologic role of relatively low doses of radioiodine and a dramatic increase in thyroid cancer in children
- Polish data support the use of KI as a safe and effective means to protect the public against thyroid cancer caused by internal exposure to the thyroid from inhaled and/or ingested radioiodine when exposure cannot be prevented by evacuation, sheltering, or food or milk control.

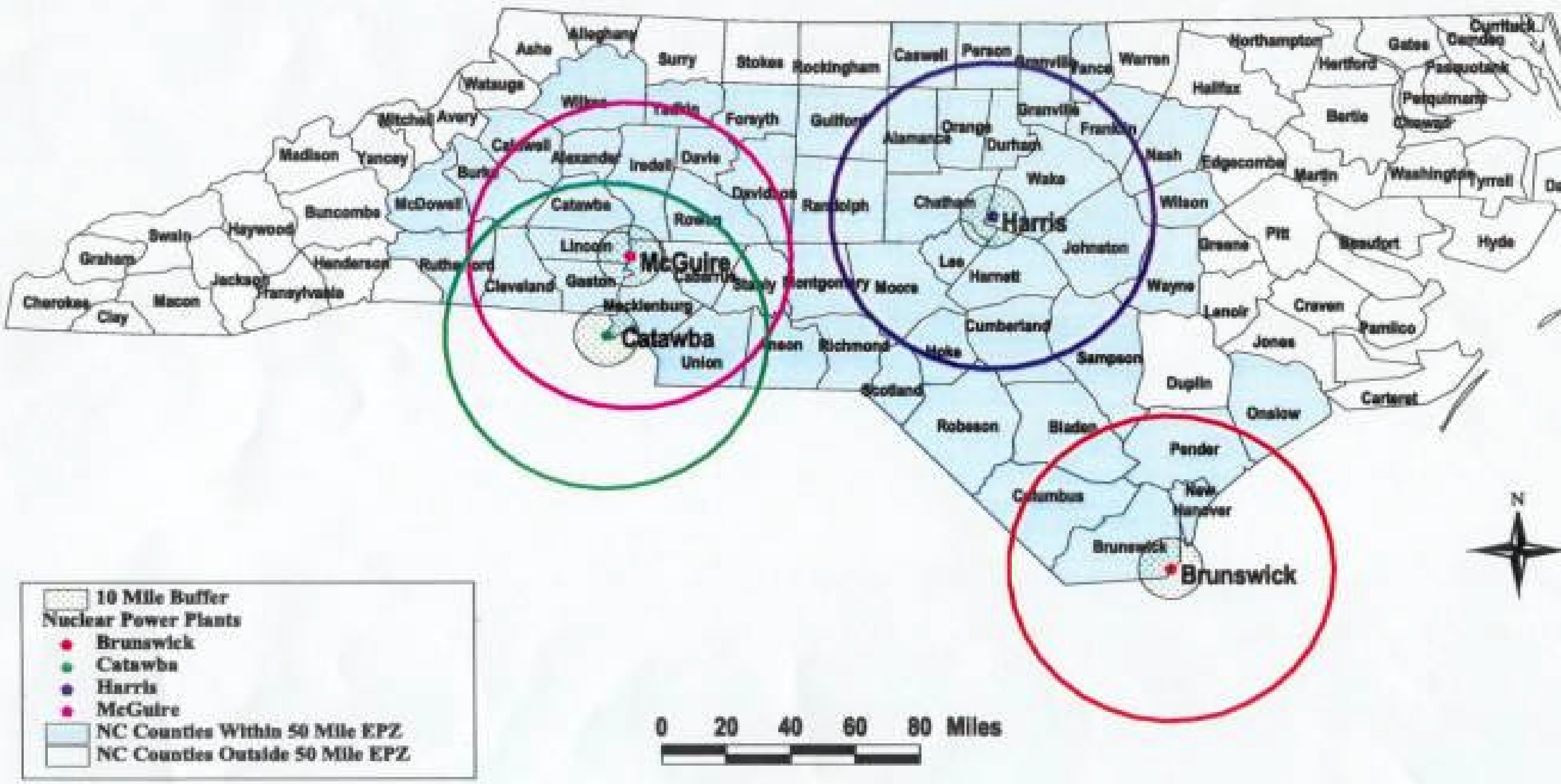
Chernobyl: Lessons Learned

- "If the population had been immediately advised to not drink milk and to avoid fresh locally produced green vegetables, and if stable iodine had been effectively distributed, especially to the youngest children, the thyroid consequences of the Chernobyl accident would have been very greatly reduced." Sir E. Dillwyn Williams, MD, FRCPath Keynote Address, Current Status of the Radiation Impact of the Chornobyl Nuclear Accident on the Thyroid. American Thyroid Assn Sponsored meeting. Washington, D.C. February 28, 2003.

Risks to the Thyroid from I ^{131}

- **Thyroid cancer**--especially among children
  - Chernobyl data strongly suggest inverse association with age--the younger the child at the time of exposure the greater the risk
- **Hypothyroidism** in children and adults at high levels of exposure

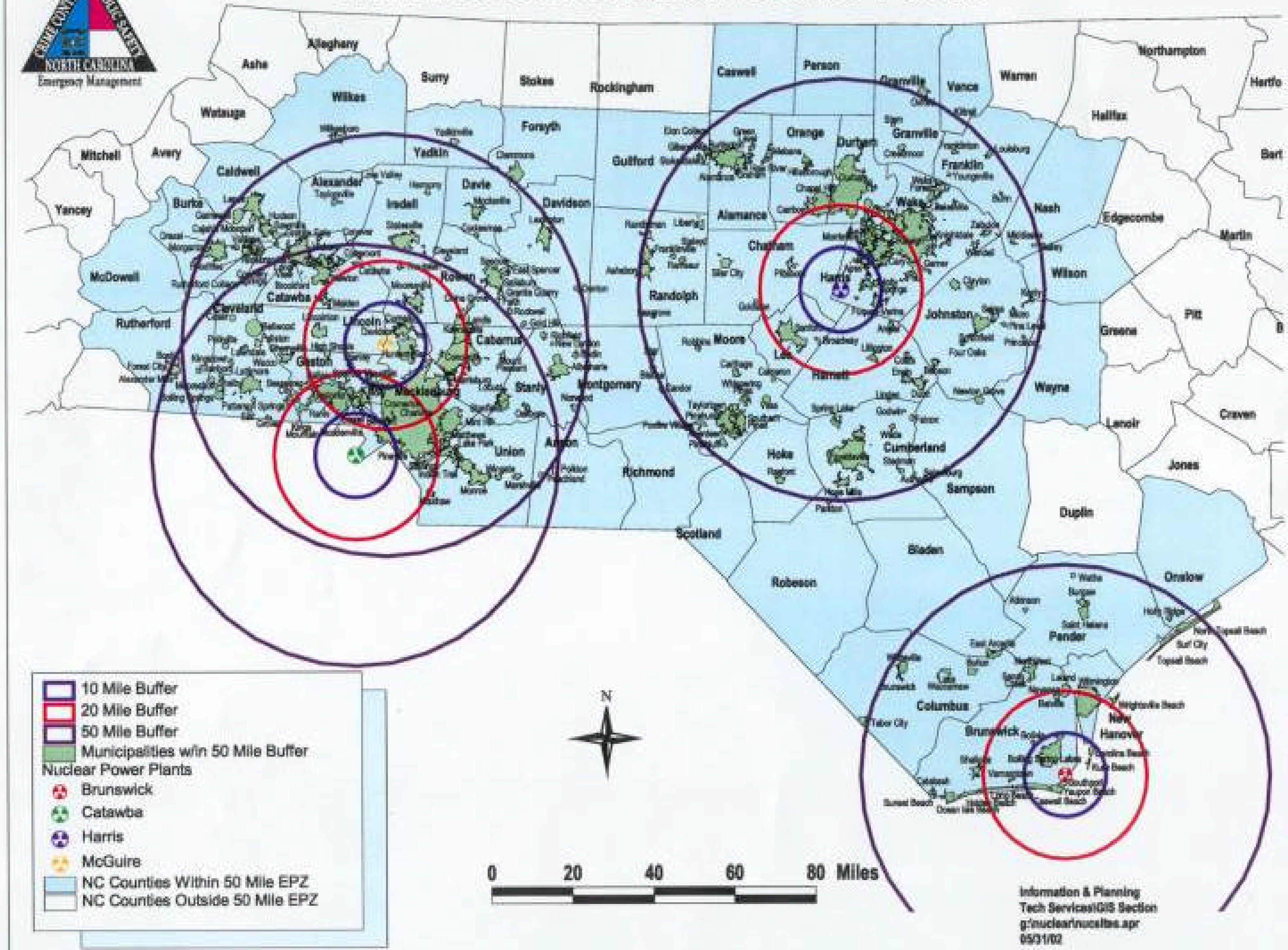
North Carolina
Utilities Nuclear Power Plants



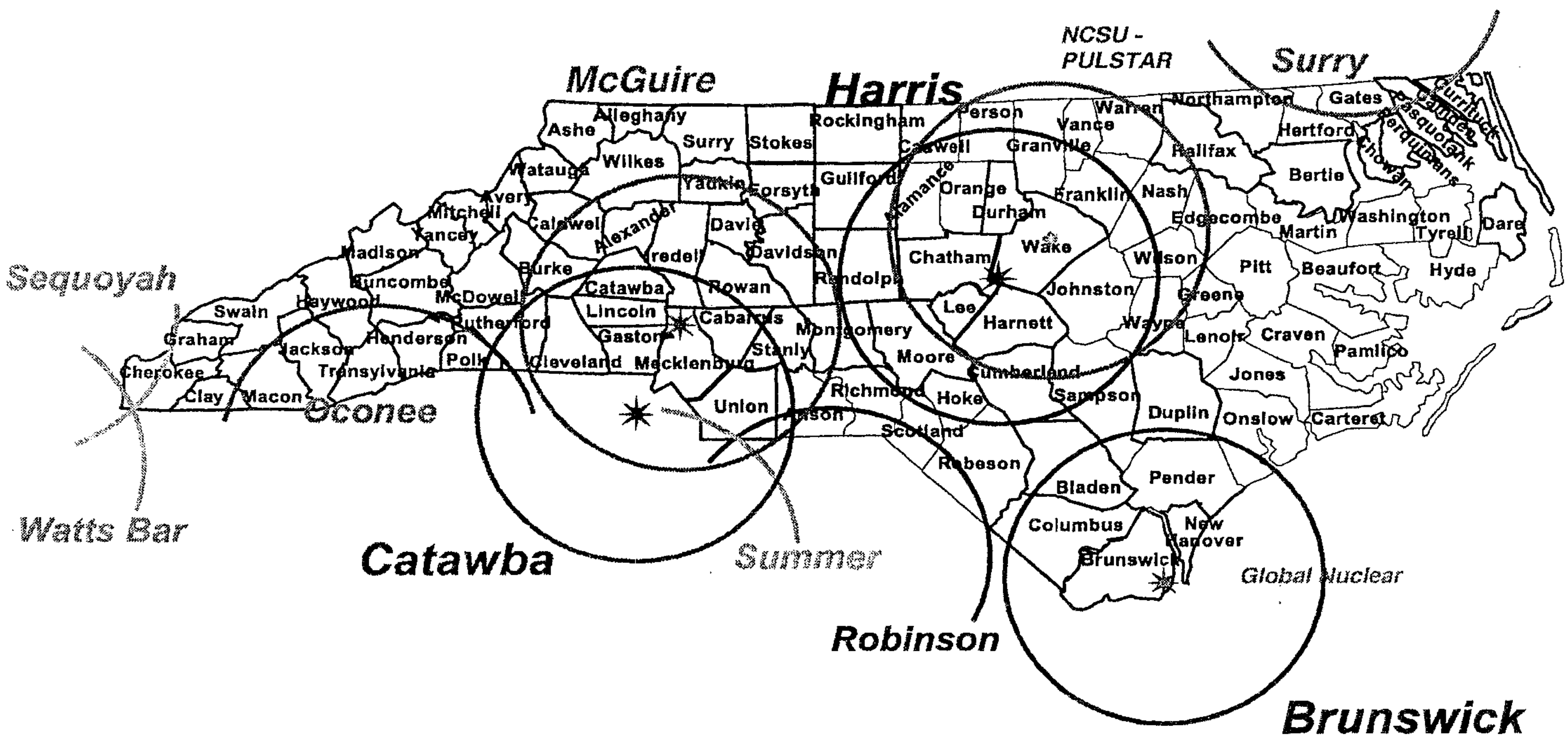
10 Mile EPZ Counties

- McGuire Nuclear Power Plant
  - Mecklenburg, Lincoln, Gaston, Catawba and Iredell Counties
- Catawba Nuclear Power Plant
  - Mecklenburg and Gaston Counties
- Harris Nuclear Power Plant
  - Wake, Lee, Harnett, Chatham Counties
- Brunswick Nuclear Power Plant
  - Brunswick and New Hanover Counties

North Carolina Nuclear Power Plants

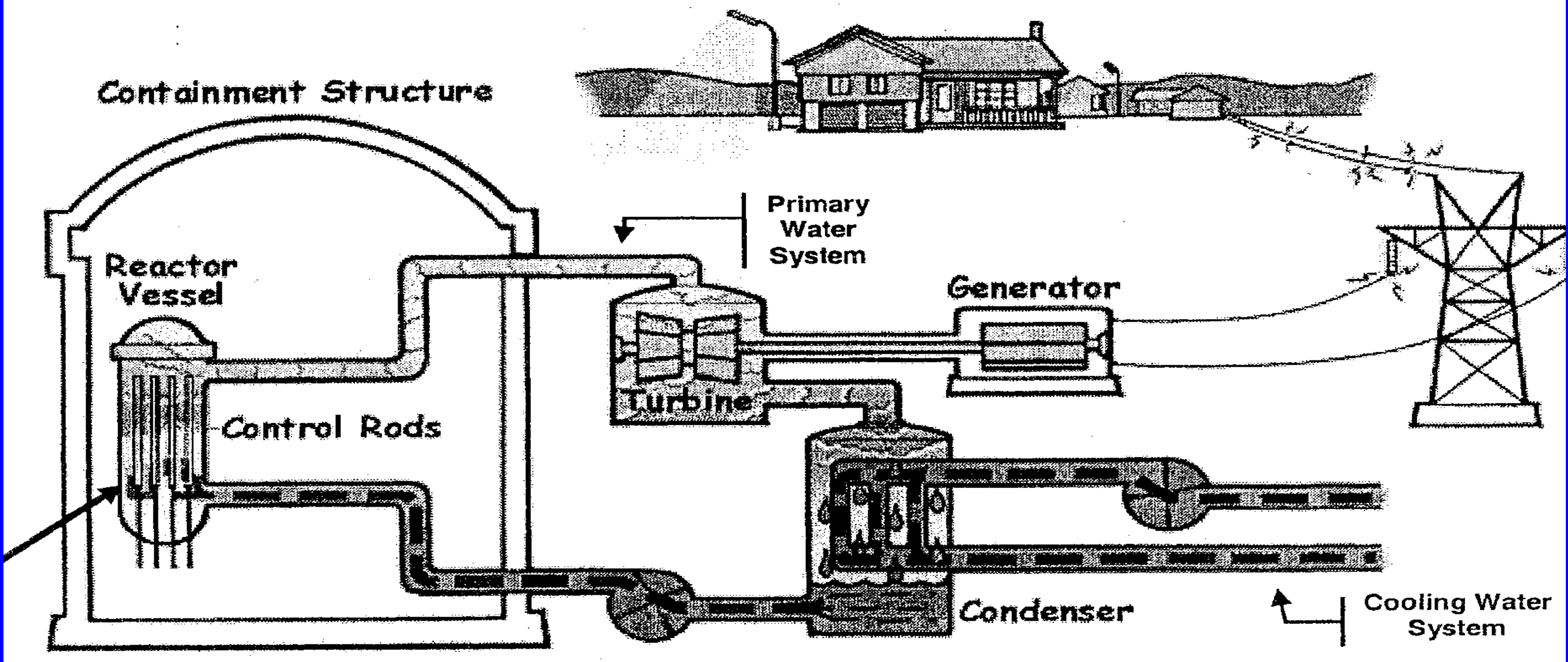


Nuclear Power Plants with 50-Mile EPZs Entering North Carolina



BOILING WATER REACTORS

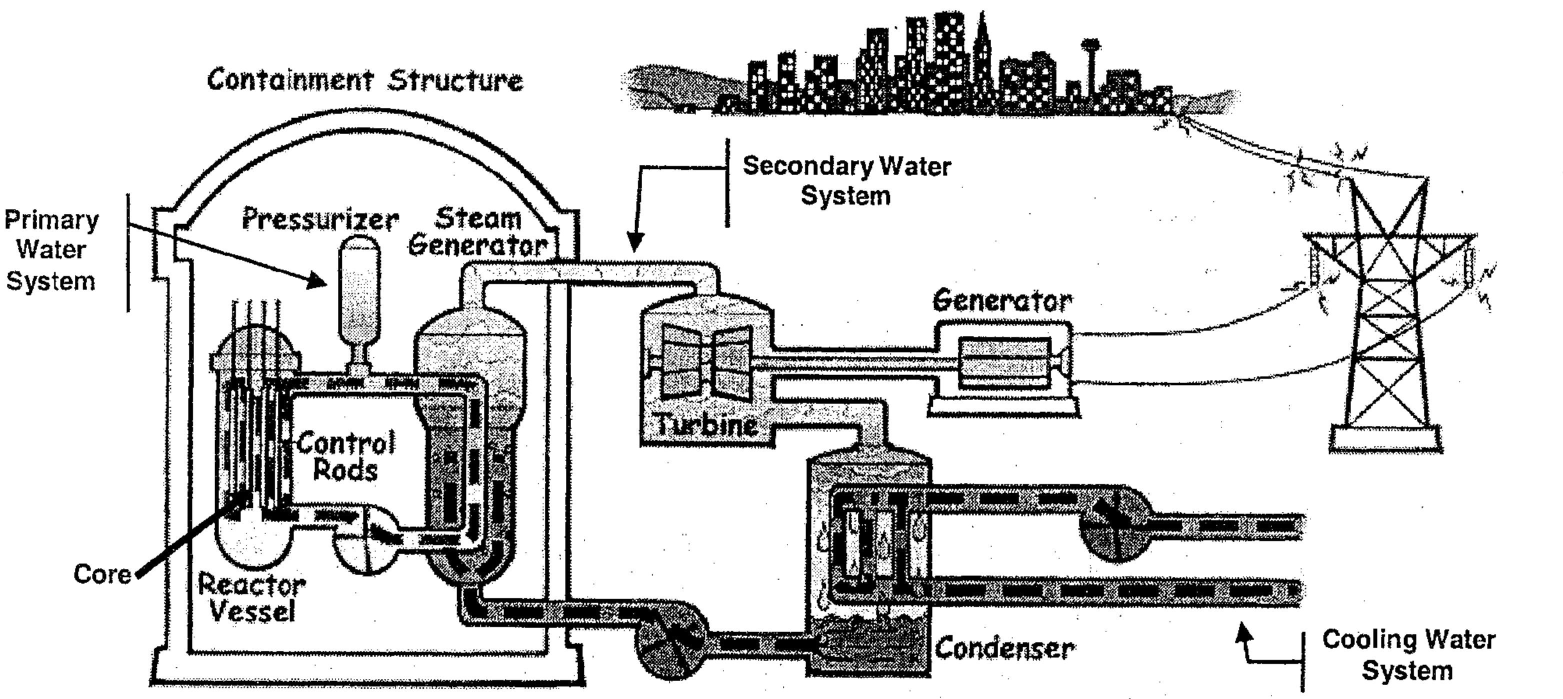
Water around the reactor core is allowed to boil and then recycled for further use. Steam drives the turbine and then goes to the condenser where it is cooled back to water and returns to the reactor core .



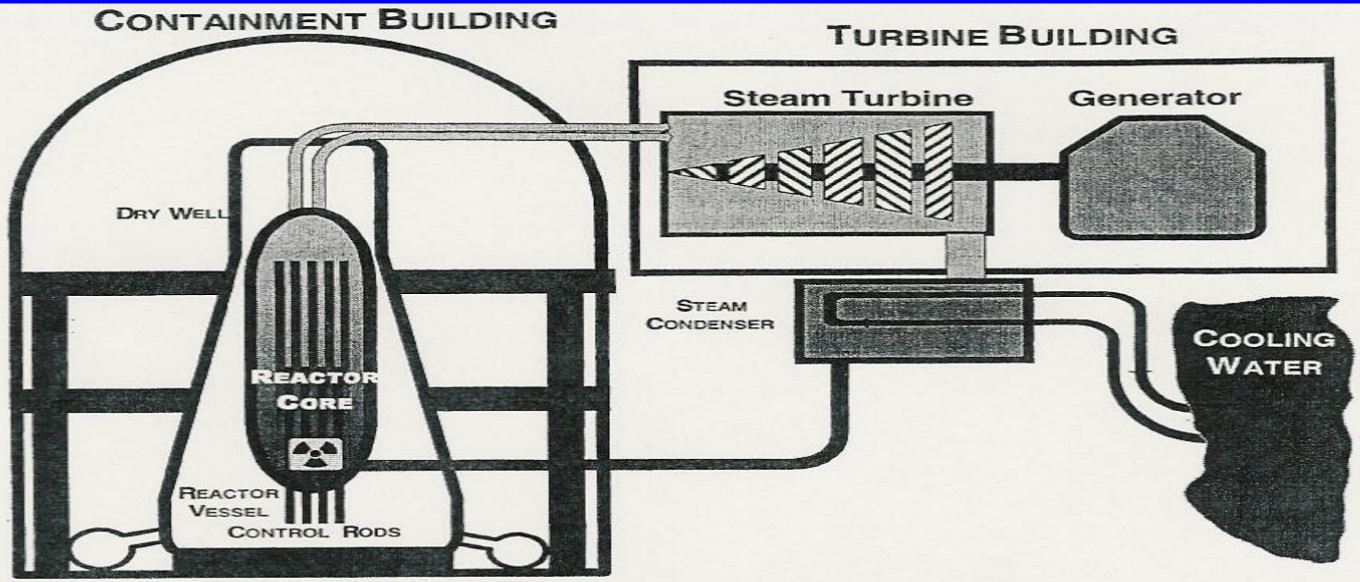
Brunswick Nuclear Power Plant

PRESSURIZED WATER REACTORS

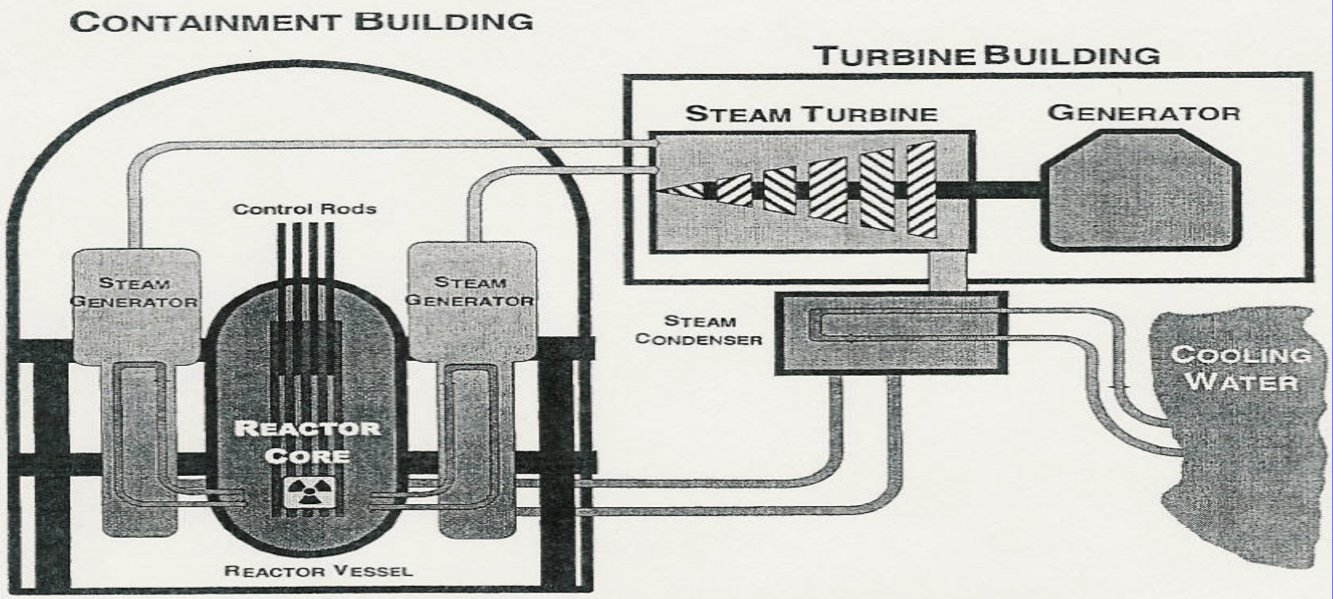
Water circulates thru the reactor core under pressure to remove heat generated from fission. Heated water leaves the reactor vessel, passes thru the coolant loop piping to the steam generators. There, the water gives up its heat to the water in the secondary loop which produces steam to drive the turbines.



McGuire and Catawba Nuclear Power Stations & Harris Nuclear Power Plant

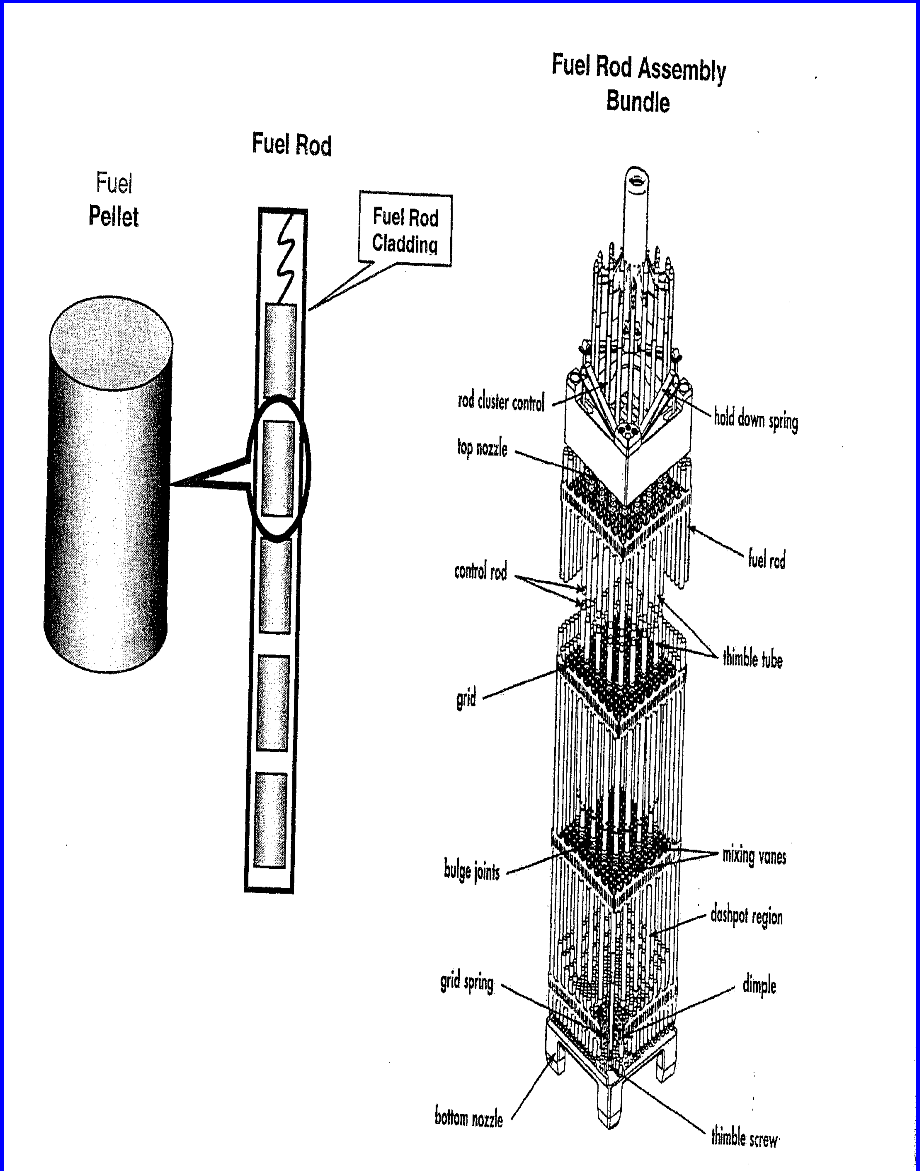


Boiling Water Reactor



Pressurized Water Reactor

BARRIERS TO THE RELEASE OF RADIOACTIVE MATERIAL



Three Barriers to Prevent Release of Radioactivity from the Reactor Core to the Environment:

- **Fuel Pellets are placed in fuel rods with zirconium cladding.**
- **Fuel Rods are assembled into bundles within the reactor vessel. Vessel and coolant system piping comprise the second barrier.**
- **Containment building is the third fission product barrier.**

POTENTIAL CORE DAMAGE CONSEQUENCES IN RELATION TO TEMPERATURE

5400 F Melting of fuel pellets (UO_2)

4800 F Release of all volatile fission products from fuel

4200 F Possible formation of uncoolable core

3800 F Formation of "liquefied fuel". Fuel dissolves into melted components

3000 F Very rapid release of iodine, cesium, and noble gases

2400 F Very rapid steam-zircoalloy reaction-release of H_2

1800 F Possible cladding burst-release of fission products in fuel pin gap

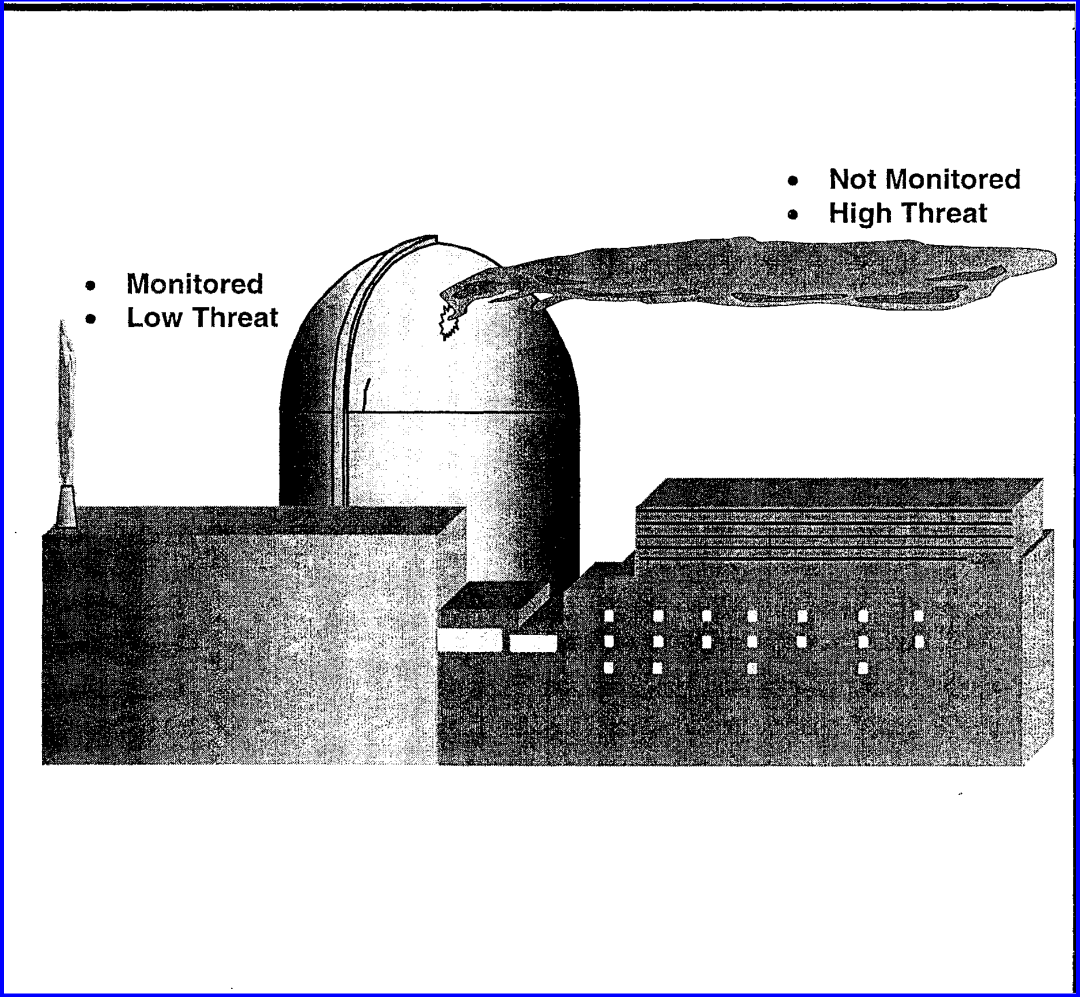
1200 F

600 F Normal operating temperature

EMERGENCY CLASSIFICATION RESPONSE ACTIONS

CLASS	PLANT ACTION	OFFSITE ACTION
Unusual Event	Provide notification	Be aware
Alert	Mobilized plant resources. Activate Technical Support Emergency Operations Faciltity and JIC	Standyby: Partial staffing of key EOC positions
Site Area Emergency (SAE)	Monitoring teams on standby. Provide reactor status and plant information	Possible protective actions. Activate sirens and EAS
General Emergency (GE)	Full mobilization. Recommend protective actions with 15 minutes of declaring a public emergency	Implement appropriate protective actions as recommended by the State.*

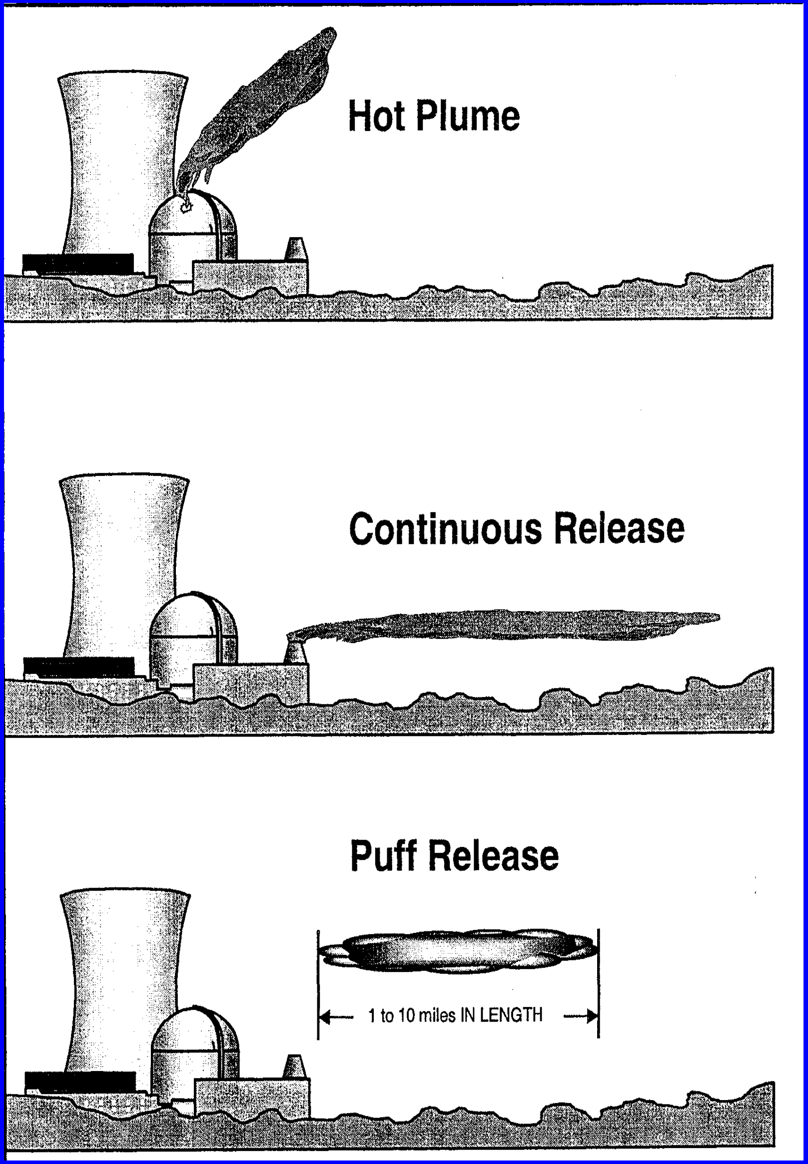
TYPES OF RELEASES



MONITORED
Release likely delayed or filtered so that most of the important fission products have been removed

UNMONITORED
Release poses the greatest potential risk for exposure and health effects

EXAMPLES OF PLUME TYPES



RADIOACTIVE PLUME

A hazardous cloud of radioactive gases, aerosol particles, and water vapor

FALLOUT

DEPOSITION of RADIOACTIVE MATERIAL

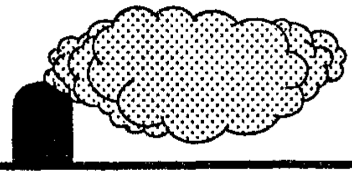
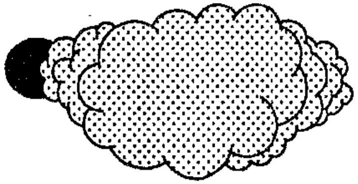
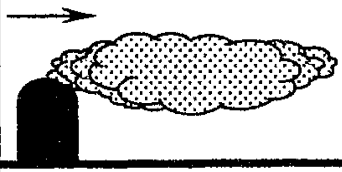
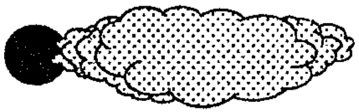
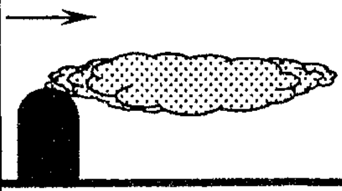
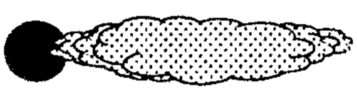
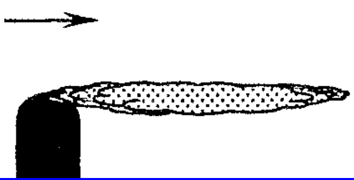
Occurs as the plume moves away from the plant.

Deposition patterns are affected by weather conditions and plume characteristics.

Technical Aspects of Plume Releases

- **Types of Releases**
  - **Puff (short duration < 2 hrs)**
  - **Continuous (extended duration)**
- **Variables Affecting Release**
  - **Release Rate (function of source, containment, vent flow rate)**
  - **Release Height**
  - **Transport (influenced by wind direction and speed, atmospheric stability and precipitation)**
- **Type of Exposure**
  - **External (Immersion-noble gases, Cloud shine, Ground Shine)**
  - **Internal Inhalation-- Immersion (particulates, aerosols)**
    - **Resuspension (particulates)**
    - **Ingestion--Contaminated water, milk, food products**

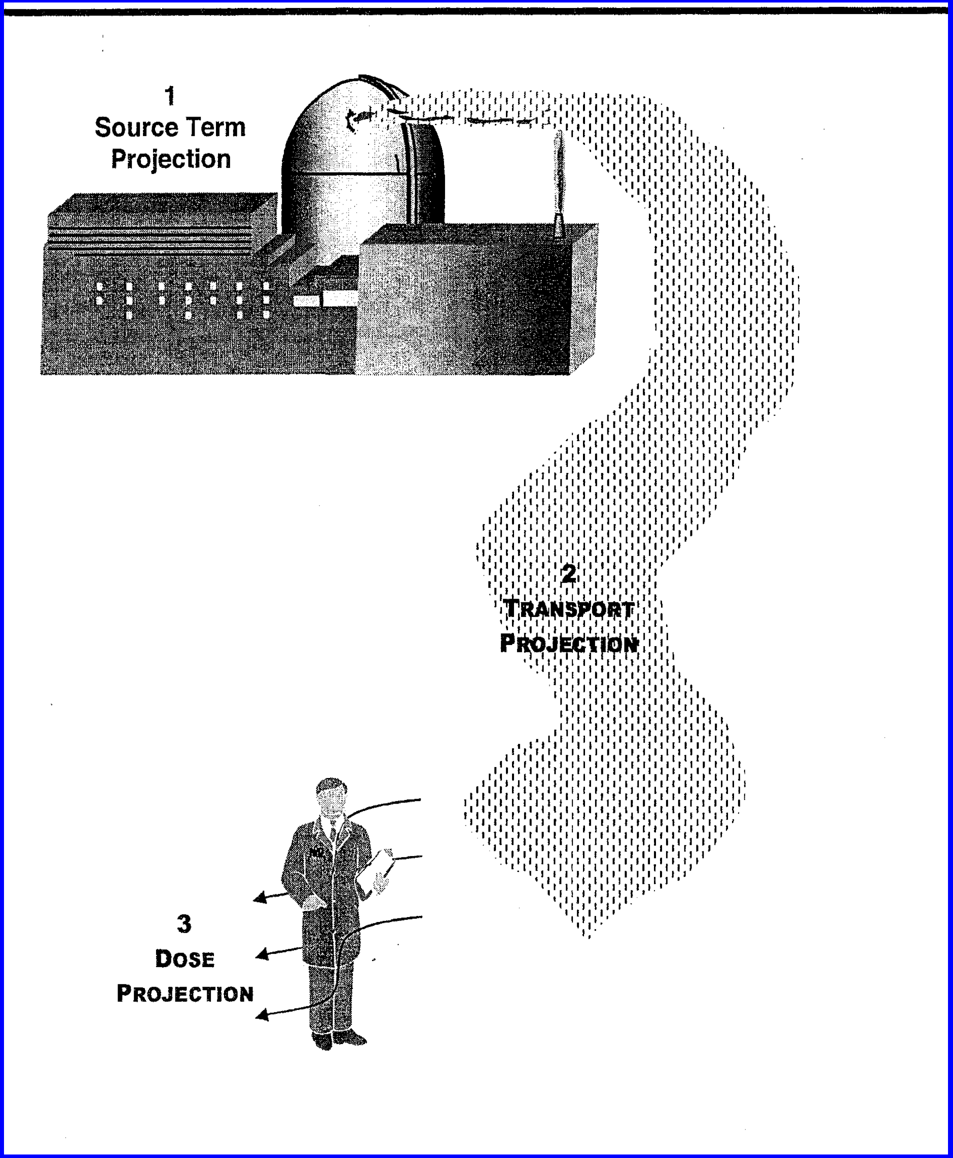
CLASSIFICATION OF ATMOSPHERIC STABILITY

Stability Class	Type	Plume Characteristics: Description	Side View	Top View
A,B,C	Unstable	Day Time Occurrence with Mostly Sunny to Sunny Skies and Moderate Wind Speeds		
D	Neutral	Normally Found During Day or Night with Overcast Skies and Moderate Wind Speeds		
E, F	Stable	Overcast Skies, Precipitation Conditions, or Clear Night Time Skies with Light Wind Speeds		
G	Very Stable	Found only During Night (Most Likely Around Sunrise/Sunset with very Light to Calm Wind Speeds		

Critical Human Exposure Factors Related to Risk from Plumes

- **Whole Body Exposure**
  - Internal
  - External
- **Thyroid Exposure**
  - Inhalation
  - Ingestion
- **Exposure to other Organs**
  (muscle tissue, bone marrow,etc, primarily via ingestion)

PREDICTING DOSE

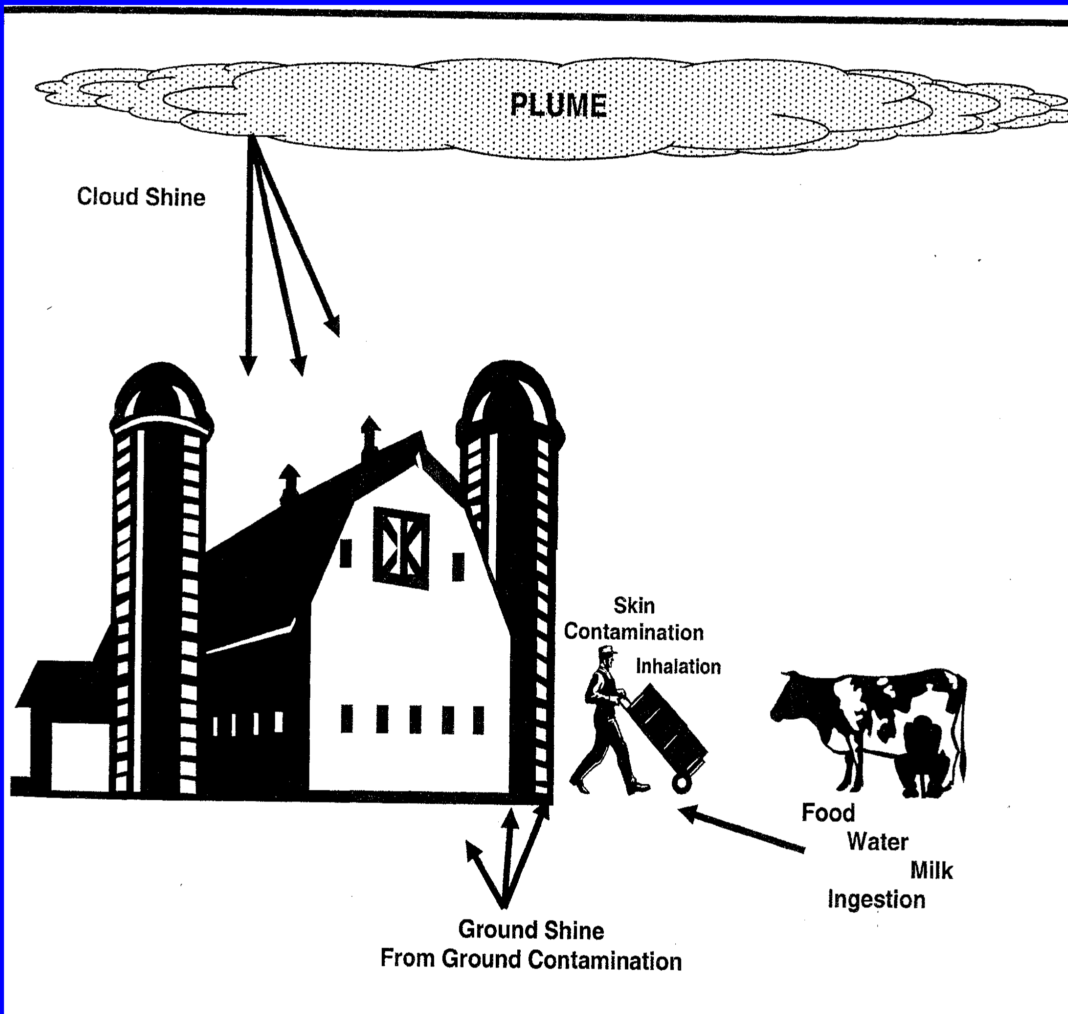


SOURCE TERM Projection
Predicting the quantity of radioactive material and the timing of the release

TRANSPORT Projection
Predicting the movement of the plume

DOSE Projection
A function of internal and external exposure

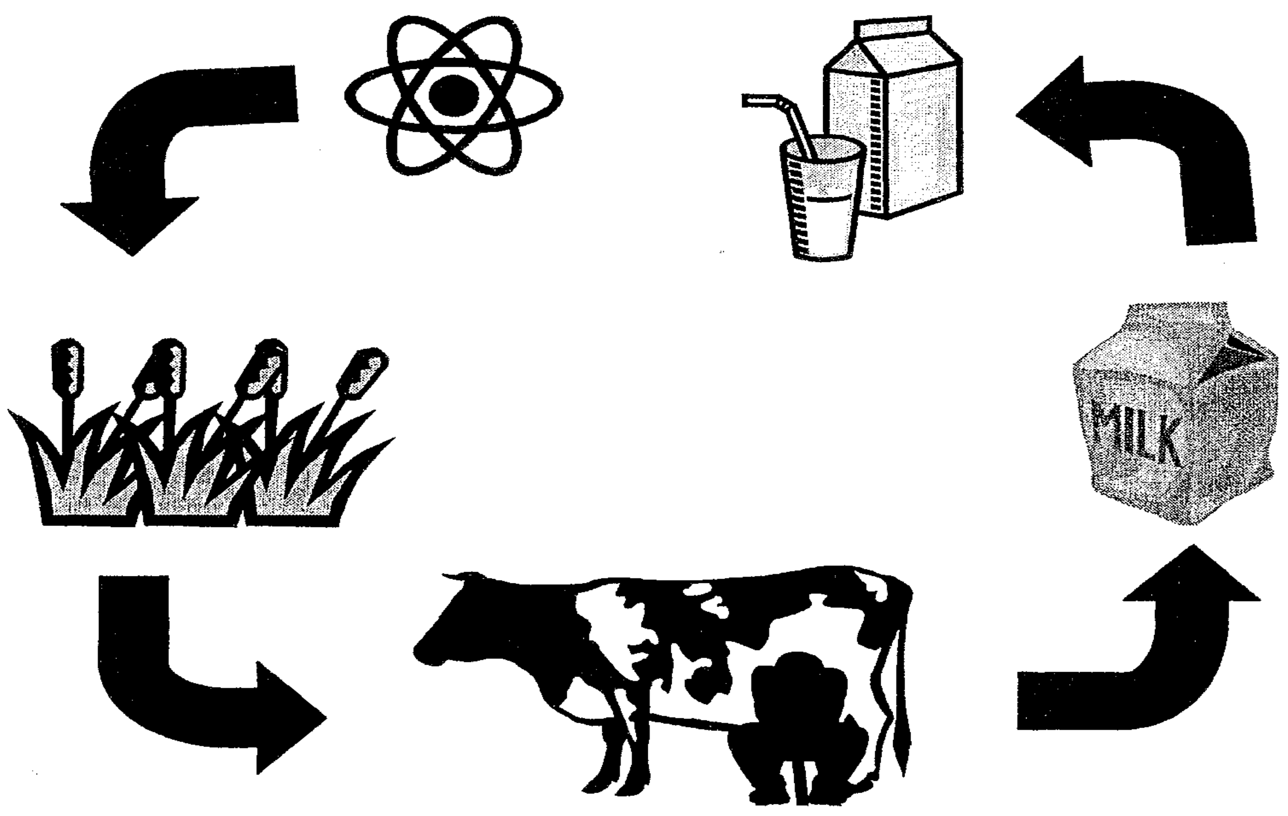
RADIATION DOSE PATHWAYS



- **EXTERNAL**
  - Skin contamination
  - Cloud shine
  - Ground shine
- **INTERNAL**
  - -INHALATION
  - - INGESTION
    - Food
    - Water
    - Milk

Ingestion Pathway Example

Internal Exposure



INGESTION PATHWAY EXAMPLE = MILK

Ingestion Pathway Protective Actions

- **Precautionary Protective Actions**
  - Actions to embargo food products in a geographical area until measurements from food and water samples are made and actions to place milk-producing animals on stored feed and protected water.
- **Preventive Protective Actions**
  - Actions to prevent or minimize contamination of milk and food products based on EPA protective action guides **(Example: Washing, scrubbing, and peeling fruits and vegetables to remove surface contamination)**
- **Emergency Protective Actions**
  - Actions to isolate, contain, or destroy food to prevent its introduction into commerce

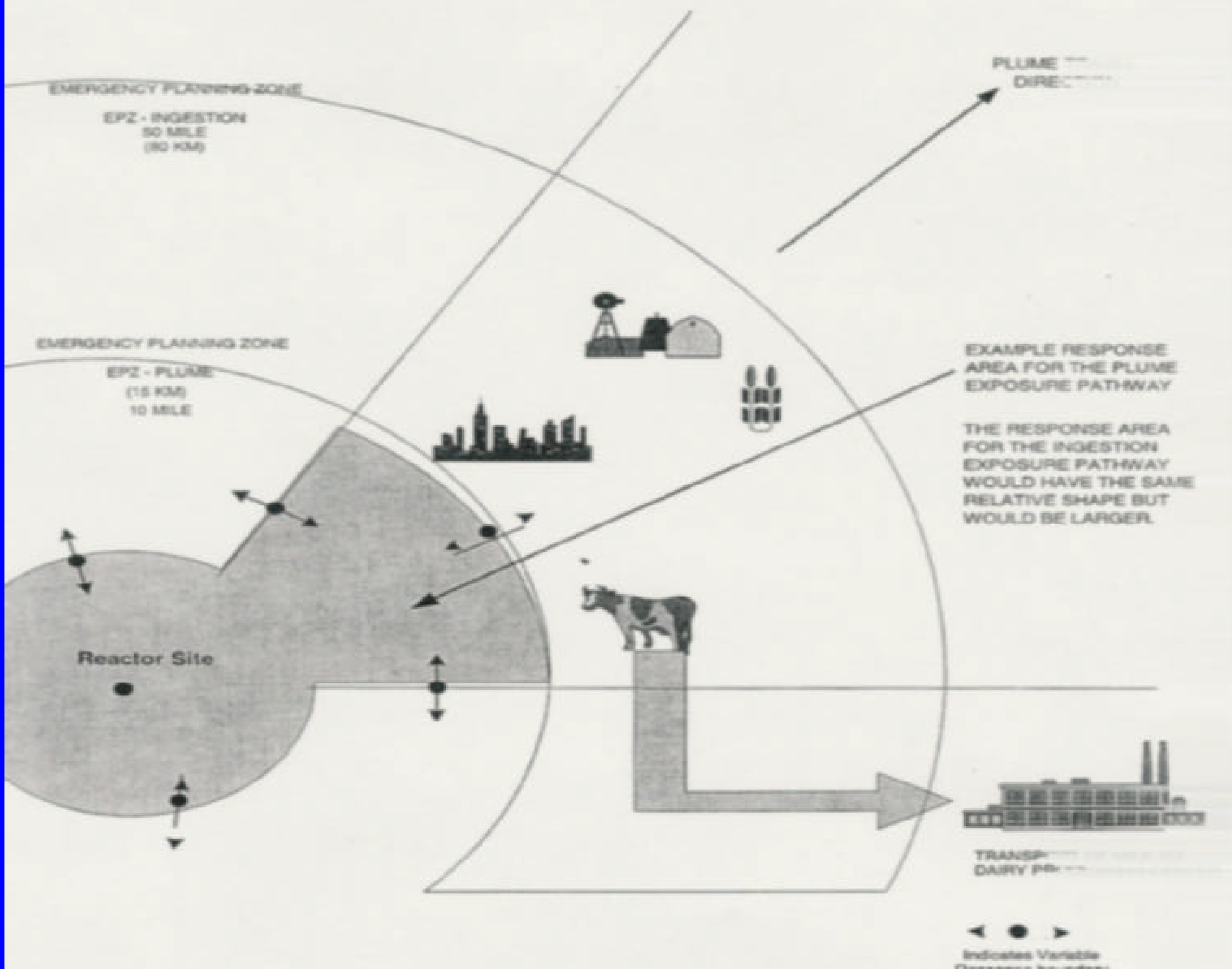
Emergency Planning Zones

Established by NRC for emergency planning purposes

- Plume/Inhalation Exposure Pathway (Primary)
  10-Mile EPZ
- Protective Actions
  - **Evacuation**
  - **In-Place Sheltering**
  - **Access Control**
  - **Distribution of KI**
  - **Decontamination**

- Ingestion Exposure Pathway (Secondary) 50-Mile EPZ
- Protective Actions
  - **Placing Dairy Animals on Stored Feed and Water**
  - **Sampling of Food Products (farms, food processors, etc)**
  - **Food Interdiction**
  - **Process / Hold Food Products for Future Sampling**
  - **Special Handling Information on Fruits and Vegetables**

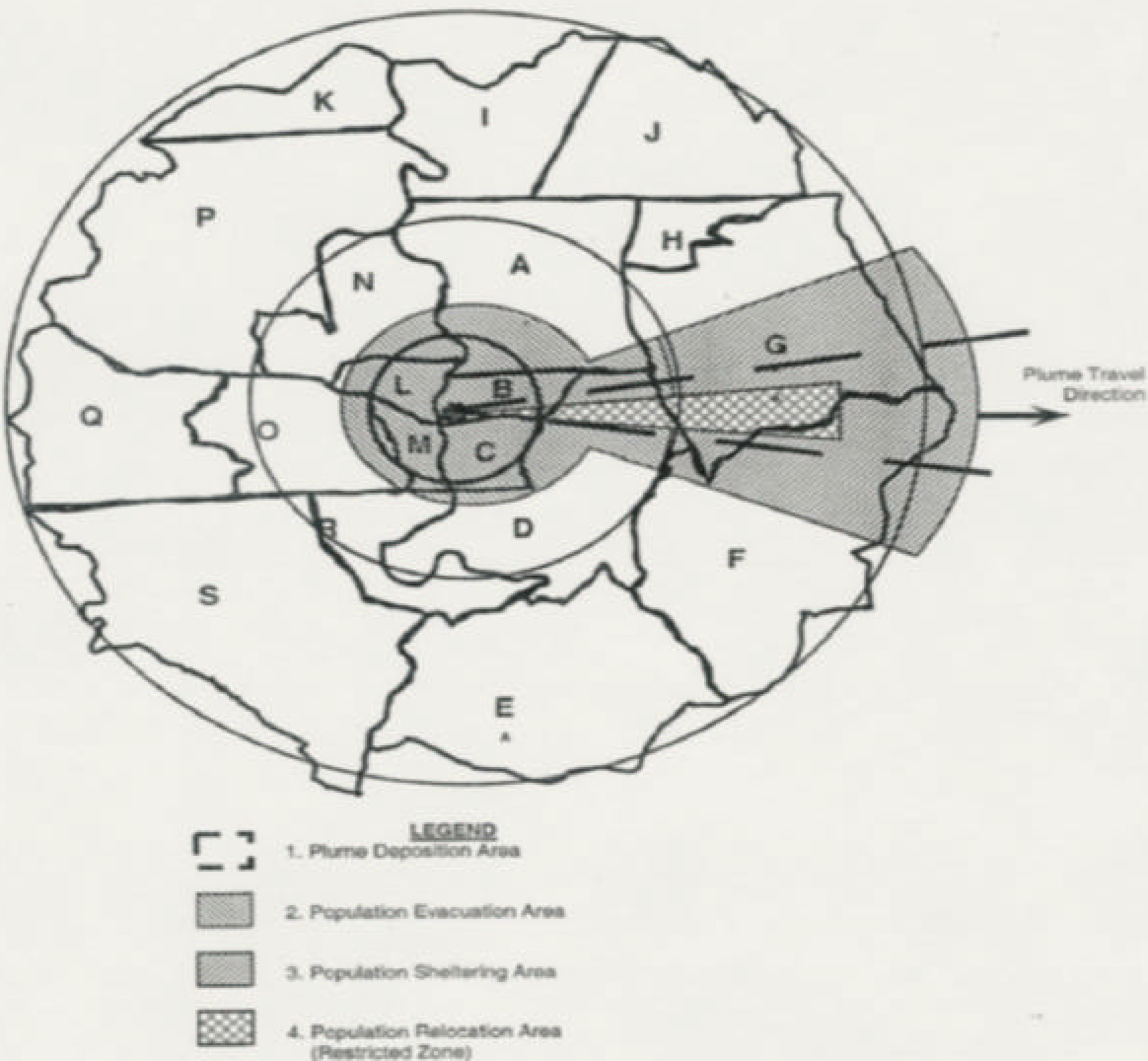
CONCEPT OF EMERGENCY PLANNING ZONES



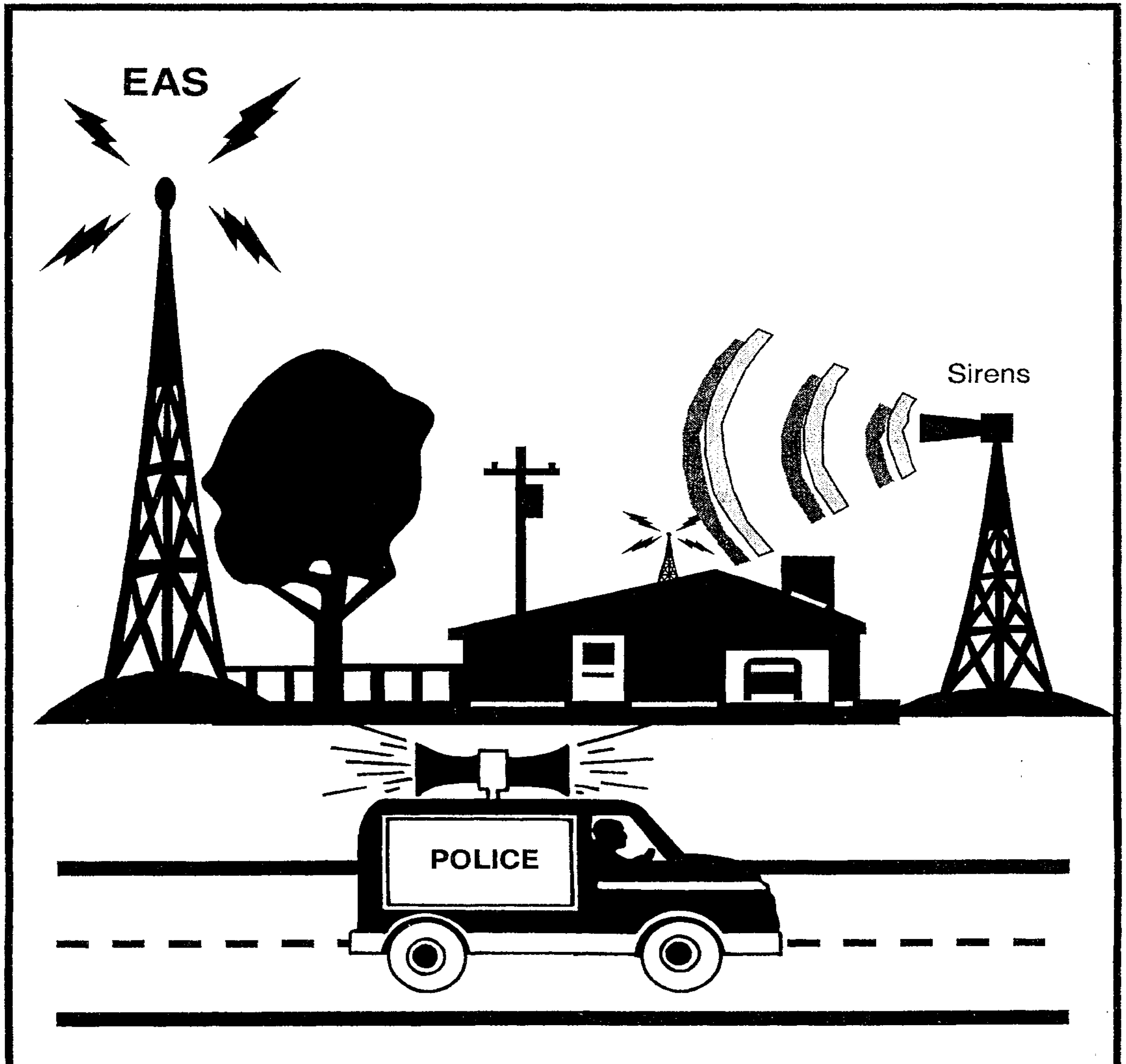
TYPICAL "KEYHOLE"

Protective actions are usually applied to an area referred to as a "keyhole". This "keyhole" represents an area in all directions from the plant (typically a 2 mile radius) and in the downwind direction (typically 5 miles downwind).

10 Mile EPZ



Public Alert and Notification



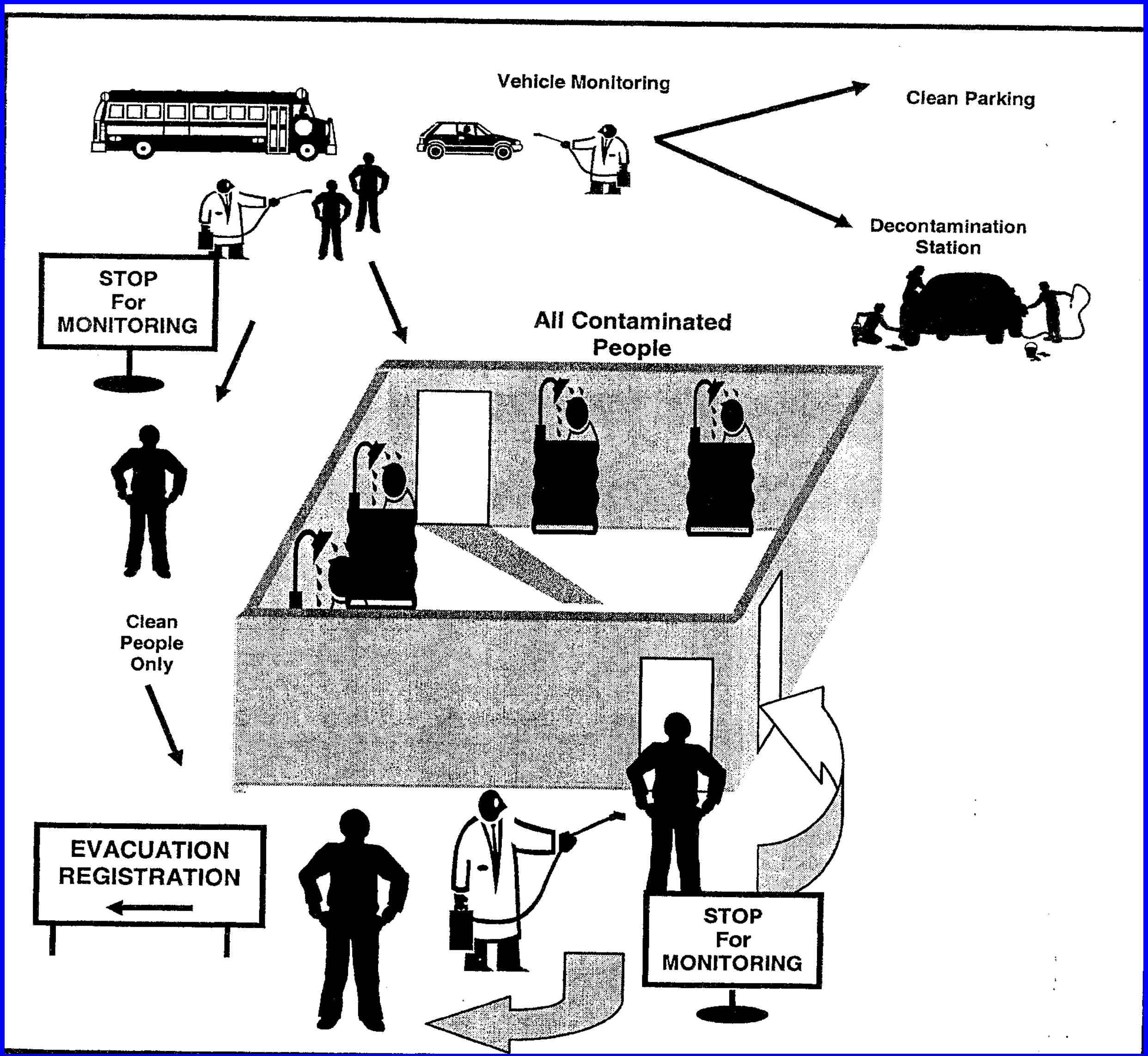
- **Local Government** is responsible for all warning within county
- **Utility** may recommend
- **SERT** may order

- **Primary Notification**
  - Fixed siren system
  - 10 mile-EPZ
  - Emergency Alert System
- **Secondary Notification**
  - Tone-Alert Radios
- **Back-up Route Alerting**
  - PA system
  - Door-to-door

Notification

- **Primary Notification:** fixed siren system; activation controls in county communications center, designed to warn immediately all areas in the 10 mile EPZ; will sound 4 times for period 3 minutes each; thereafter depends on judgement of official in charge
- **Emergency Alerting System:** activated 3 to 5 minutes after siren system; allows time for public to access TV and radio
- **Secondary Notification:** Tone-Alert Weather Service radios automatically alarm with siren activation; will broadcast emergency instructions to public
- **Back-up Alerting:** Vehicles with sirens or public address systems streets; door-to-door for hearing impaired

Reception Centers-outside 10-mile EPZ



Evacuees:

- Registration
- Monitoring
- Decontamination

Number of Centers is based on 10-mile EPZ Population

Prophylactic Use of KI

- Supplements Evacuation and Sheltering
- Goal is to saturate the thyroid with stable iodine before a person is exposed to radioactive iodine

Efficacy of KI
Time is of the Essence

- Effective in reducing the uptake RAI when taken before, during or shortly after exposure to radioiodines via inhalation and/or ingestion
- For optimal protection against inhaled radioiodines it should be administered before or coincident with passage of the radioactive plume
- May still have some protective effect if taken 3 to 4 hours post exposure

FDA

- Definitive Medical Authority in the United States on the Use of Potassium Iodide

SAFETY AND EFFICACY OF KI

- 1978
  FDA reaches general consensus KI is a safe and effective means to block uptake of radioiodines by the thyroid in a radiation emergency
- 1982
  FDA issues final recommendations on the administration of KI to the general public in a radiation emergency

1982 FDA Recommendations

- Formulated on estimates of external thyroid irradiation after nuclear detonations at Hiroshima and Nagasaki and review of studies of children who received head and neck irradiation for treatment of medical conditions.
- For projected doses of $\geq$ 25cGy from inhaled or ingested radioiodines, benefits of preventing radioiodine induced thyroid cancer outweighed the risk of low dose KI
- Recommended dose 130mg/day >1 year old;

65 mg/day children < 1 year old

FDA Recommended Prophylaxis

Age and Predicted Thyroid Exposure

December 10, 2001

• Adults over 40 years	$\geq$ 500 cGy
• Adults over 18 through 40	$\geq$ 10 cGy
• Pregnant or lactating women	$\geq$ 5 cGy
• Adolescents	same
• Children	same
• Neonates	same

North Carolina KI Prophylaxis Guidelines

- First Responders
  Any indication of RAI exposure from the event- Administer KI
- Institutionalized Populations
  Data indicating thyroid RAI exposure of $\geq$ 5 rad- Administer KI
- Children
  Data indicating thyroid RAI exposure of $\geq$ 5 rad- Administer KI.
- Adults (Interim)
  Data indicating thyroid RAI exposure of $\geq$ 5 rad- Administer KI

FDA Recommended KI Dose by Age
December 10, 2001

Age Group	KI Dosage	Amount of 130 mg Tablet
Adults over 18 years	130 mg	1 tablet
Over 3-18 years *	65 mg	1/2 tablet
Over 1 mo-3 years	32 mg	1/4 tablet
Birth to 1 month	16 mg	1/8 tablet

*Adolescents approaching adult size 70 kg (150 pounds) should receive a full tablet (130 mg).

Duration of Dosing

- Protective effect of KI lasts approximately 24 hours
- For optimal prophylaxis, persons (other than neonates and pregnant and lactating women) with predicted exposures equal or greater than those noted previously should be dosed daily until the risk of significant exposure to radioiodines via inhalation or ingestion no longer exists.

Contraindications to Short Term Administration of KI

- **Known iodine sensitivity**
- Two rare conditions associated with an increased risk of iodine hypersensitivity
  - Dermatitis herpetiformis
  - Hypocomplementemic vasculitis

Possible Side Effects of KI

- Allergic reactions--RARE
- Gastrointestinal distress-- 2%
- Minor rashes--1%
- Sialadenitits--rare

Possible Thyroidal Side Effects of KI

- Iodine-induced thyrotoxicosis-more common in older people and in iodine deficient areas and usually requires repeated doses of stable iodine.
- Iodide goiter and hypothyroidism-more common in iodine sufficient areas but these require chronic high doses of stable iodine.
- Persons with multinodular goiter, Grave's disease and autoimmune disease should be treated with caution, especially if dosing extends beyond a few days.

Precautions
Pregnant Women and the Fetus

- Stable and radioactive iodine readily cross the placenta.
- Pregnant women should receive KI for their own protection and for that of the fetus.
- Due to the risk of blocking fetal thyroid function with excess stable iodine, repeat dosing with KI in pregnant women should be avoided
- Repeat dosing in neonates should be avoided

Precautions
Lactating Women and Infants

- Lactating females should take KI for their own protection and to reduce the radioiodine content of breast milk, but not as a means to deliver KI to infants, who should receive KI directly
- Like direct administration of KI, stable iodine as a component of breast milk may also pose a risk of hypothyroidism to nursing neonates.
- Repeat dosing with KI should be avoided in the lactating mother except in severe contamination
- If repeat dosing of the mother is necessary, monitor the neonate’s thyroid function

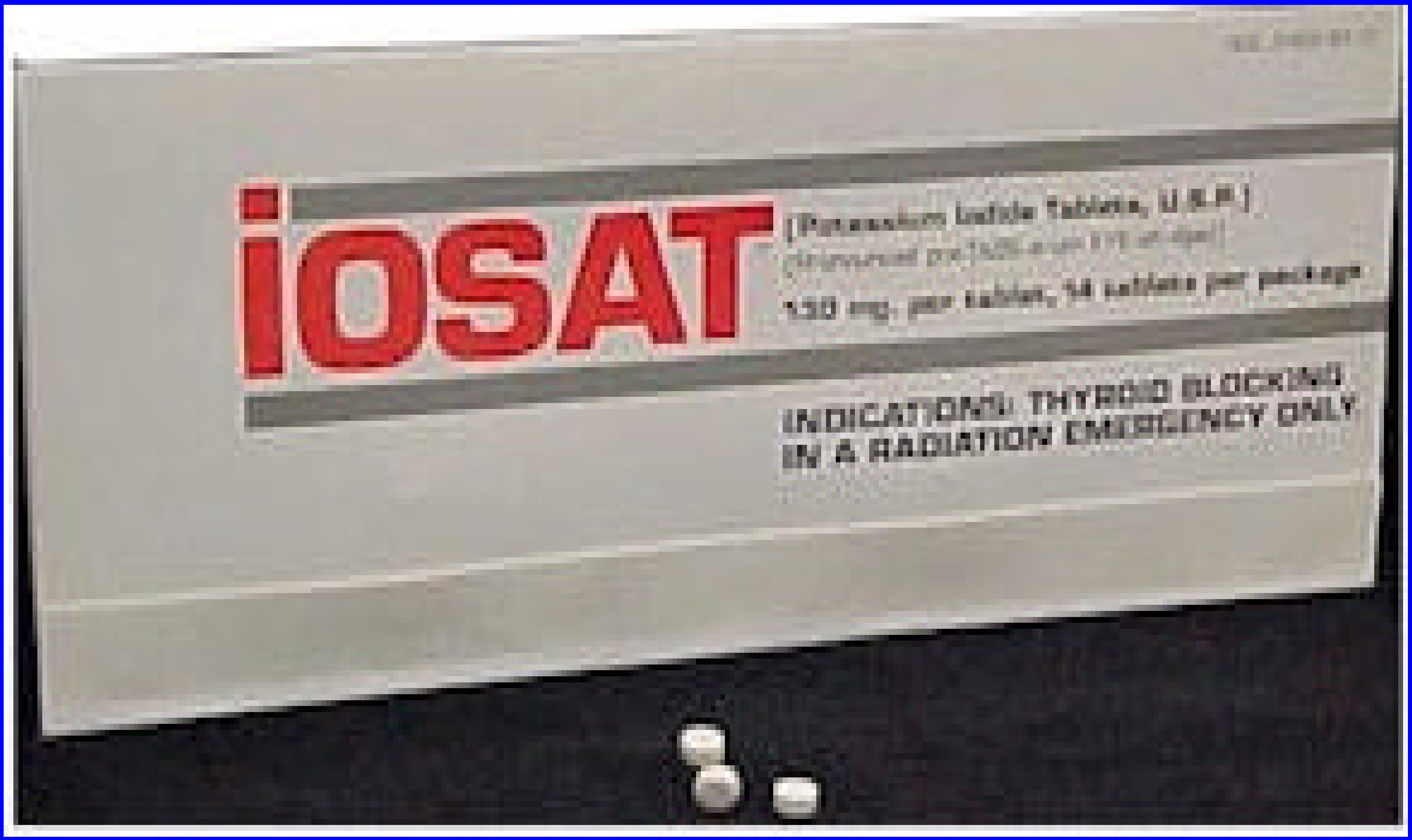
Monitoring of Neonates

- Poland experience: Transient hypothyroidism was observed in 12 of 3214 neonates treated with KI following the Chernobyl accident in 1986.
- No reported sequelae to date
- FDA has determined that benefits of KI outweigh the risks for the neonate.
- FDA recommends that neonates treated with KI be monitored for hypothyroidism by measurement of TSH (and FT4 if indicated)
- Thyroid hormone therapy should be started if hypothyroidism develops.

FDA Approved OTC KI Products

- Iosat 130 mg scored tablet shelf life 5 + yrs
  - Distributed by Anbex, Inc.
    - 866-463-6754
    - www.anbex.com
- Thyro-Block
  - Distributed by MedPointe, Inc
    - 732-564-2200
    - www.medpointeinc.com

Potassium Iodide 130 mg



Nuclear Regulatory Commission

- Makes emergency preparedness regulations
- Rule change effective April 19, 2001
- Amends 10CFR50.47(b)(10)
- Requires states with populations within the 10-mile EPZ of commercial NPPs to consider including KI as a protective measure for the general public to supplement sheltering and evacuation in the unlikely event of a severe NPP accident

KI Distribution in North Carolina

- **Pre-event**
  - First Responders
  - Institutionalized Populations w/in 10-mile EPZ
  - Residents within the 10-mile EPZ
  - Major Industries/Employers w/in 10-mile EPZ
  - Schools/Day Cares within 10-mile EPZ
- **Post-event**
  - Not completely developed at this time
- **Annex K -NC EOP**

REMEMBER - In a NPP Emergency:

- **EVACUATE, if instructed to do so.**
- KI, if indicated, is a protective measure that supplements evacuation and sheltering.
- KI only protects the thyroid. It does not protect other organs or tissues.
- KI does not protect against external radiation doses from the plume or radioactive materials deposited on the ground.
- KI does not protect against internal doses due to other radionuclides such as Cesium 137.

Precautions for the Family

- Keep food and water in a closed area of your house where it cannot be contaminated by fallout. Eat canned and shelf foods first.
- Eggs, potatoes, melons, and other fruits and vegetables that are cleaned may be eaten.
- Wash green leafy vegetables carefully; remove outer layers.
- Peas and beans require normal cleaning.
- Don’t consume contaminated dairy products
- Wash hands thoroughly before eating.

Agricultural Precautions

- Shelter all farm animals especially dairy cattle and goats
- Feed livestock only protected feed and stored or uncontaminated water if possible
- Bring feed into buildings or cover outdoor feed supplies
- Store as much water as possible for livestock. Cover wells, rain barrels and tanks.

References

- **World Health Organization (WHO 1999)** Guidelines for Iodine Prophylaxis Following Nuclear Accidents: Update 1999
- **Food and Drug Administration (FDA 2001)** Guidance: Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies December 2001
- **FDA/Center for Drug Evaluation and Research:** Home Preparation Procedure for Emergency Administration of Potassium Iodide Tablets to Infants and Small Children, July 3,2002

- **Mettler FA and Voelz GL**. Major Radiation Exposure-What to Expect and How to Respond. New England Journal of Medicine 2002; 346(20)1554-61(May 16, 2002).
- **American College of Radiology.** Disaster Preparedness for Radiology Professionals August 31, 2002 www.acr.org
- **National Council on Radiological Protection.** Management of Terrorist Events Involving Radioactive Material. NCRP Report 138. October 24, 2001
- **Armed Forces Radiobiology Research Institute**. Pocket Guide for Responders to Ionizing Radiation Terrorism. www.affrri.usuhs.mil

More Information

NC Department of Health and Human Services KI website (general information and copy of the Potassium Iodide Information Sheet):
www.dhhs.state.nc.us/dph/ki.htm

NC Department of Health and Human Services June 28, 2002 press release
www.dhhs.state.nc.us/pressrel/6-28-02a.htm

Guidance: Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies USDHHS, FDA, Center for Drug Evaluation and Research, December 2001
www.fda.gov/cder/guidance/4825fnl.htm

Prophylactic Use of Potassium Iodide (KI) in Radiological Emergencies: Information for Physicians.
www.health.state.ny.us/nysdoh/ki/ki_md.htm

More Information

- Health Physics Society <www.hps.org>
- American Thyroid Association <www.thyroid.org>

The End